# Psychological Optics

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Introduction
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# INTRODUCTION

For some time it has been growingly apparent to those who have to deal with the eyes and their function that optics, and even physiology, are only preliminary and preparatory phases of vision; that, ultimately, vision and visual reactions are an affair of the mind, and an exceedingly complex psychological affair, at that. It is not, in the end, the image that is registered on the retinae or in the occipital cortices, but the image which emerges from all the associative and organizing processes of the mind, some innate and some acquired, that shapes and determines the visual reactions.

It is true that the borderline between physiology and psychology is a very indefinite one, and not easy to distinguish. Such a distinction, however, even if it could be made, is not the important consideration. The all-important thing is that when the visual impulses register themselves in the so-called conscious areas of the brain, producing visual sensations, their effects are not confined to the centers in which they first register, but spread, by associative pathways, to practically all other centers, arousing a veritable complex of mental reactions. It is in the light of all these associations and memories and interests that the visual sensations are interpreted, and by their net, selective resultant that the reactions are shaped and determined. And this, in the end, constitutes the psychology of vision.

The same truth pertains, of course, to every sense, and particularly to what are commonly known as the special senses. To vision, perhaps, it has a peculiarly high degree of application, partly because of the continuousness (or almost that) with which, during waking hours, visual sensations obtrude themselves on consciousness, partly because of the large and varied part that vision plays in our relations with the external world—larger and more varied, probably, than that of any other sense.

From a clinical standpoint the psychological factors of perception, attention, interest, emotions even, play a determining role in those neuro-muscular reactions and coordinations which nowadays form so important a field of visual investigation and training. They must be reckoned with in our test methods, in the interpretation of our findings, and in the devices we employ for re-education.

In order to deal understandingly with visual reactions and their defects, therefore, it is necessary to have an understanding of the psychological principles and processes of stimulus-response behavior, especially as these relate to vision. And to this end it is important that we have a textbook on the subject adequately adapted to the needs of the student and the practitioner who are professionally concerned with this particular phase of psychology. There has, of course, been plenty of valuable work done in this line, and there are many excellent sources of data, as is attested by the numerous references appended to this book. The need has been rather for a somewhat simplified, organized presentation of the subject for the use of the student and of the man in the field.

Although I had no part in the conception or the materializing of this book—I neither fathered nor mothered it· I did enjoy a sort of avuncular privilege of watching it grow, chapter by chapter, until it emerged into its maturity. This, however, merely gave me a favored pre-knowledge of its character. Now, at its "coming out," anyone may see, as well as I do, that the author has met the needs of the situation in a highly satisfactory fashion. It is a workman-like book, making no extravagant pretensions, but giving a faithful account of psychological optics in a sufficiently clear and practical form for the educative and professional use for which it is intended, and should be a welcome contribution to this class of literature. Author and publisher are to be congratulated upon filling a long-felt requirement.

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## Chapter I

# THE REACTION PRINCIPLE OF BEHAVIOR

Psychological optics, or the psychology of vision, is to be regarded as merely one of the many departments of general psychology. It is the study of the mental side of vision, as distinguished from physiological optics, which is properly the study of the physiological processes involved in seeing. Distinctions of this sort are not sharply drawn in practice, however, for physiological optics entails considerable study of the anatomical structures concerned in the physiology of vision, and similarly an elementary foundation of visual physiology is needed for an understanding of visual psychology.

Since, furthermore, visual psychology is a special field of general psychology, a number of the broader facts and formulas of behavior must be understood in order that they may serve as premises for the approach to the detailed problems of the visual process. It is believed that such a grounding is definitely essential to a comprehension of the mental factors in vision. The patience of the reader who is more or less exclusively interested in visual psychology must therefore be solicited in this chapter and in the one to follow, which are devoted to a review of fundamentals.

Probably the most comprehensive doctrine of contemporary psychology is that all behavior consists of *reactions*. The psychologist does not view behavior as a unified whole—at least to begin with—but rather attempts to analyze it into its component parts. By this procedure he arrives at its elements—the simplest forms in which it occurs, behavior in its natural entirety being far too complex for profitable study. These elements are called reactions, and behavior may be analyzed, for example, into emotional reactions, motor reactions, memory reactions, visual reactions, etc., in somewhat the same way that

physiology separates the total activity it studies into nervous, circulatory, respiratory, digestive, etc., processes. The study of individual reactions, then, is the only way to an understanding of the enormously involved processes of behavior as they go on in concrete "everyday" living. Obviously, until we can understand the simplest forms in which a phenomenon occurs we can hardly hope to grasp its more complex instances.

Behavior, accordingly, is to be considered as a mass of more or less separate, or at least separable, reactions, and these reactions, moreover, are always the consequence of some sort of *stimulation.* A *stimulus* is anything that arouses an individual to any kind of activity; his reaction or *response* is any activity which is the consequence of stimulation. Very nearly as simple a reaction as can be imagined occurs when light strikes the retina. One becomes aware of an impression of brightness or luminosity. The light, as a physical agency, is in this case the stimulation; the brightness impression is the reaction or response, and merely being aware of something is to be regarded as a response to it, even though the stimulation may have no further consequences. Such a further consequence might take the form of squinting, closing the eyes, or raising the hand to shade them; in this event muscle or *motor* responses, as well as conscious responses, would be said to follow upon stimulation. Simple as such events are, they constitute behavior, and their significant feature at this point is that they illustrate the fundamental character of *all* behavior, namely, activities of the organism aroused by the stimulation of *receptors* or sense organs, the eye being outstanding among these structures. This activity of the organism may, as in the above example, consist of consciousness and of movement; it might also include an emotional reaction or a glandular response. The last statement, in fact, covers all of the possibilities in the way of reactions; the consequence of any type of stimulation will be either some kind of conscious experience, some variety of movement, some sort of glandular activity or, more commonly, a combination of all of these, as in emotion.

The source of stimulation in the case of vision consists of objects in the external world. The stimulus itself is not the object but rather the physical energy which it sends to the receptor, which may be the eye, the ear, or the sense organ of

smell and temperature, all of which enable us to respond to objects at a distance. Impressions of touch, taste, and pressure, on the other hand, are reactions produced by objects in contact with the body, but specialized sense organs are involved in the reception of stimulation in these cases as well. While a distinction is sometimes made between receptors which are affected, like the eye and the ear, by objects at a distance, and those requiring contact, like touch and pressure, the difference is not a sharp one. The experience of heat, for example, may come to us from the sun or from an object held in the hand. The stimulus here, however, is a form of energy radiated by the object, in either case, and is to be distinguished from the object itself.

The organism's response to such stimulation may be, as stated above, a conscious impression, as of color, flavor, melody or coldness; a movement of the body as a whole or any of its members; or a glandular secretion, as when the mouth waters in response to the taste or odor of food. All three of these fundamental forms of reaction may occur in even so simple an instance as the events following the placing of food in the mouth. One becomes aware of the taste; the muscles of the tongue and jaws move in chewing; the salivary glands respond with their fluids.

One of the broadest generalizations that can be made about behavior is that it exhibits, universally, these two phases; it is a stimulation-reaction sequence or process. The statement is as true of the most complex activities as it is of the simplest items, such as those mentioned above. A third fundamental feature of all behavior which is in evidence even in its simplest forms, is a relationship between the two processes of stimulation and reaction. Normally the reaction is *adapted* to its stimulation, which means that the reaction is of such a character as to be useful to the organism in some way. The reaction serves a purpose, has utility, does some good, is "practical." The squinting which follows stimulation by a bright light is a defense against the unpleasantness of too much illumination. The spasms of muscle reaction in a cough blow harmful irritants out of the throat. Putting on an overcoat keeps the body temperature at a comfortable level. Eating as the response to the stimulating pangs of hunger is obviously an adaptive or useful act in

relation to both the comfort and the needs of the organism. It is difficult to think of a human activity which does not serve, immediately or finally, to satisfy some desire or to remove some source of annoyance. While such satisfactions may not always coincide, of course, with what is in the long run biologically beneficial, they may none the less be said to represent the fulfillments of some form of need, and are therefore essentially adaptive.

The impression must not be gained that the energy of individual activity is *supplied* by stimulation—that there is any dynamic equivalence between the two. The stimulus merely releases energy stored up in the organism itself, first in the receptor and thereafter in the various structures whose activity expresses in the different modes of behavior. The effect of stimulation has been compared to that of a pull on the trigger of a gun. It touches off the organism's own resident energies. The trainman's call of "All aboard" may arouse a vastly greater output of energy in the belated traveler than that represented by the physical effects of the call on his eardrums. The sight of a clock dial as he enters the station supplies an infinitesimal amount of energy to his retinas, but arouses great activity in his leg muscles. Reaction is everywhere dependent on previous stimulation, but the relation is one of release rather than a quantitative transfer of energies.

The statement so far might give the impression that everything a person does represents simply the arousal of reactions by the sights, sounds, pressures and temperatures whose sources are in the world about him. The briefest observation of behavior shows that this is not true. An enormous number of activities appear to have no external stimulation, to lack any explanation whatever in such terms. We get up and walk without being called and when every outside circumstance might favor our remaining seated; we talk without being questioned, and in general engage in a vastly greater variety of activities than can possibly be accounted for by variations in external stimulation. Clearly, if the stimulation-reaction formula is valid, many stimuli must have their source *within* the organism itself. Such internal stimuli as hunger, thirst, fatigue, pain, sex, and many others must be added to sights, sounds and pressures to furnish an adequate stimulus basis for behavior.

The triggers of action are inside as well as without, and there must be sense organs, correspondingly, within the body as well as on its surface. Sometimes the internal or *intraorganic* stimulus is adequate almost alone to account for a sequence of behavior, as when the hungry animal restlessly explores the environment for food. The reactions of eating, however, involve a combination of internal and external stimulations: food of the proper appearance, odor and taste, along with the pangs from within. The investigation of desires, motives, "instincts," is essentially concerned with these internal stimuli. Most human activity is the resultant of two types of agencies working together.

Intraorganic stimuli thus underlie innumerable activities which are either not at all or at least incompletely accounted for by excitation of the surface receptors. Changes among the internal processes of the organism may, moreover, very vitally affect the character of responses to the environment. Internal conditions, that is, may determine not only *whether* a reaction is to take place, as when the presence or absence of thirst determines our reaction to a glass of water, but also *how* we react, once a response is evoked, e.g., how much water we will drink after the drinking begins. A fit of anger may leave us in an irritable mood which changes the character of our reactions to new stimulations unrelated to those which originally aroused the emotion. Thus the business man, incensed over an unfortunate transaction at the office, may be impatient and "touchy" with his family in the evening. A depressed mood resulting from a discouraging experience may transfer to other situations and affect more or less profoundly the manner of the reactions made to them. Intoxication may for a period shift or incline all reactions in the direction of cheerfulness and buoyancy, irascibility, or melancholy.

An internal factor which profoundly influences our reactions to stimulation is indicated by the word *attention*. The majority of reactions require the giving of some degree of attention to the stimulus, and the direction of attention is strongly influenced by what we are interested in. What we *see*, as will later be pointed out, depends largely on what we are looking for. Vision and the mental state of attention are very vitally related. Innumerable potential stimuli fail to evoke reactions

only because attention is otherwise engaged. Preoccupation with one visual impression will inhibit responses to many others which would otherwise register changes in behavior. While intently reading a book we may fail to hear and therefore fail to answer a question directed to us. On the other hand a newly aroused interest will sensitize our reactions to many hitherto more or less indifferent stimuli. Thus a woman trying to decide which one among the season's hat styles to purchase will be unusually "hat conscious" until she manages to make up her mind; she will "see" (i.e., respond to) the hats on passers-by much more frequently, more critically and discriminatingly. The character of external stimulation may often, of course, be the primary factor in determining the direction of our eyes; visual fixation will be at times almost wholly a result of the location and movements of a conspicuous object; external stimulus and ocular response will be directly related in a simple fashion. The fact to be emphasized at this point is that such incidents in visual behavior are probably less frequent than those in which fixation expresses primarily the attentive state of the moment—when a particular interest, which is an internal factor, is the explanation of a particular ocular movement—when we look *at* an object only after first looking *for* it.

Among the intraorganic stimuli which cause, modify or in some manner influence behavior are those which represent the persisting effects of previous stimulation. The organism is itself constantly being changed by its own behavior. Yesterday's reactions leave imprints which carry over to affect today's responses. The face and words of the person who recently aroused unpleasant emotions may come before us again as "memories" which rearouse, though more weakly, the same emotions. We may respond, thus, to the memory images of visual impressions and to the memory echoes of auditory impressions in a way very similar to our earlier responses to the external originals. Waking in the morning, the *thought* of an early engagement will lead to a quick rise out of bed and to energetic dressing movements. The thought of a favorite food when we are hungry may stimulate a noticeable glandular reaction. Many can recall reveries in which imaginary conversations were held and silent answers given to self-supplied stimuli. Thoughts, therefore, must be included among the possibilities of stimula-

tion; from the viewpoint of the reaction principle a thought is first and foremost a stimulus and capable of arousing any one or more of the major forms of reaction.

The statement that for everything a person does, thinks or feels there is somewhere a stimulus in the absence of which the act, thought or feeling would not have occurred emphatically does not mean that in every such case the stimulation is *known*. If this were true psychology would be a completed science and the only task remaining would be to explain and apply it. The reaction principle is rather a fundamental assumption on the basis of which psychological investigation and experiments are founded. There is every reason to believe that failure to find the stimulus in any given instance is owing to failure to look in the proper place for it, or to the extreme complexity of human behavior itself, and the fact that not all behavior problems can be experimentally approached. There is still much uncertainty, for example, about such things as temporary and "unreasonable" variations of emotional moods; about the strangely unrelated thoughts which occasionally come to the mind uninvited, or the occasional curious failure of the memory to supply familiar names and facts when they are wanted; about the "stimulus" for the highly interesting and imaginative mental activities called dreams, and about many other mental events which seems to happen "for no good reason." However, the many reactions for which a more or less adequate account *can* be given provide as many promises for an eventual extension of the reaction doctrine to those which still, in appearance at least, stand beyond its bounds.

Visual psychology is of course not concerned with such problems as the above; its scope is very limited and confined to the study of those reactions which constitute visual consciousness and ocular movements. The visual functions, nevertheless, are to be regarded as a system of reactions, each of which has its adequate stimulus, and here as elsewhere in the organism the premise will be that no visual event, sensory or motor, is ever spontaneous or self-caused, and that every ocular reaction is traceable to a known or at least a knowable antecedent.

Behavior begins, then, with stimulation either outside or within the organism, or with both, and consists of the three types of reactions outlined. These reactions, again, are of such

a nature as to be useful to the organism with reference to its needs and the character of stimulation. The responses are designed to adapt the organism to its environment, which means to serve its wants or preserve it from injury. Specialized physiological structures exist in the body whose function it is to provide for the three phases of reaction. These structures are the sense organs or receptors, which receive stimulation; the *nerve centers* of the central nervous system, whose function is to *select* an adaptive response; and the response organs or *effectors*—the muscles and glands. It is the muscles, most importantly, which *effect* changes in the environment. Little mention of the glands will be necessary in psychological optics. Vision, from the viewpoint of psychology, may be regarded as a process consisting of conscious impressions and of muscular adjustments. Being conscious of something, as stated earlier, is a way of responding to it, and the gray surface-tissue or *cortex* of the brain, whose activity generates conscious experiences, is therefore one of the organs of response. The responses of the brain are mostly of the character of preparatory activities; at least the emphasis may be so placed at this point. It is in the brain and the other nerve centers that the decisions are made as to the muscle movements which will most satisfactorily *fit* the quality and character of stimulation. The cortex is the major organ of adaptation, the chief of all the nerve centers, and the seat of consciousness. While it is the structural basis of conscious responses it will not, however, be referred to as an effector, since it does not, like muscular movements, have any direct effects on the environment. Its response activities are simply the means whereby the organism becomes aware of the environment with its various stimulations, and the means whereby suitable responses are selected.

The function of most nerve centers, whether in the brain or in other parts of the central nervous system, is this same process of selection and decision. The more complex or "higher" centers are in communication with a greater number and variety of sense organs, and in control of more muscles, but all of them, higher or lower, are engaged in receiving the effects of stimulation (the "nerve impulses") from the receptors, and in discharging impulses to the muscles and glands. The activities of many of the centers—the relatively simple or "lower" ones, are

not accompanied by consciousness; their "decisions" are purely physiological. Those of the brain, on the other hand, do arouse consciousness. When the nerve impulses which start up in the retina, following stimulation, flow through the cells of the cortex, after having passed over the optic nerve fibres, they somehow produce the experience called a visual image, in a way which has been crudely compared to the production of illumination by current flowing through a tungsten filament.

Stimulation of the eyes, specifically of the retina, by light rays, does not arouse a visual impression. In the retina these rays release rapidly rhythmic physiological processes called nerve impulses. These impluses flow from the retina over sensory or *afferent* nerves to the brain, and during this flow there is still no vision, no seeing. Thus far the events proceed in terms of the physics of light and the physiology of the nerve process. Vision as a mental or psychological phenomenon begins with the passage of impulses through the cells of the cortex; these are the structures, accordingly, which constitute the immediate physical basis of vision. Visual images are brain cell reactions, or at least the accompaniment of such reactions. They are one of the three types of psychological responses previously listed—the conscious type. They may further be followed by a muscular response, as when the eyes rotate in pursuing the movements of an object which is the source of retinal stimulation. In this event we have an example of the response-controlling work of the nerve centers. The brain now discharges impulses to the muscles which turn the eyes, and it must discharge them in such a manner that the direction and rate of movement will be nicely *adapted* to the direction and rate of travel of the object. Assuming that it is for some reason useful to the organism to continue to see the object as it moves, the ocular rotation may thus be regarded, like all reactions, as an adaptive act.

On the *motor* or muscular side the functions of the nerve center may be characterized as distributive and coordinative. It must distribute its discharge of impulses to the muscles in such a way that the proper groups will contract—"proper" in the sense that the resulting act will accomplish something of value to the individual, as when the hand pushes away a source of unpleasant stimulation, or raises food to the mouth. A dis-

charge of impulses at random cannot produce useful behavior; the response must be specific, which means that particular muscle movements must be first selected and then combined into a smoothly working unit, each element harmoniously contributing its bit to the whole. The distribution of impulses to the eye muscles, for example, exhibits this feature of reaction to a high degree, for both eyes, in a horizontal turn, must move as a perfectly synchronized team, the muscles in each eye contracting equally in following the light source or in exploring the visual environment. Certain muscles must relax, during such rotations, while others are contracting, and a subtle balance of the opposed functions must be maintained. This delicate work of coordination, which means the harmonious control of different muscles so that they contract as a cooperating group, is a most vital part of the function of the nerve centers. Not only, moreover, must the right muscles contract, but they must contract at the right *time* and at the proper *rate,* since the movement as a whole may involve a succession of phases which must begin neither too soon nor too late if the act is to accomplish its purpose. If the eye muscles, in following a moving object, contract too rapidly, for example, the object will be momentarily lost to direct view when the "line of vision" gets ahead of the source of stimulation. Coordinated movements of the arm, wrist and fingers must likewise be properly timed, for the fingers cannot perform skillfully and effectively unless supported by the right amount and rate of extension of the arm and wrist.

Comparable work is accomplished by the centers on the sensory, as distinguished from the motor, side of behavior. Besides coordinating the muscles, they must correlate the impression furnished by the various sense organs. Out of the great mass of impressions flooding into consciousness the brain selects certain ones for "attention." Effective behavior, as was seen, would be impossible if the muscles contracted at unsupervised random; for the same reason the higher centers of the brain must choose from the chaos of sensory impressions those groups which constitute specific objects and situations answering to present interests and purposes, and exclude all others unrelated to these.

The grouping of selected and related impressions, as well as the exclusion of others, is part of this work. Experience must

be shaped into definitely patterned units—into organized wholes. A visual image, the sound of a musical chord, and a particular group of sensations of finger pressure come to us through three quite different and functionally separate receptor channels, yet we respond to them as a single unit of experience: the piano keys are seen, felt and "heard" as one event. Widely different impressions must therefore be "tied" into wholes as well as selected, themselves, out of a larger setting, in order to furnish us with experience as we concretely know it. The function of the centers in combining and organizing reactions is as clearly seen in the sensory as in the motor features of behavior.

A further instance of the operation of the nerve centers of the brain in combining reactions is manifested in its work of associating the effects of past sensory impressions with present ones. A characteristic sound from the street, for example, calls into mind the thought of an automobile in motion; the sound instantly makes me "think" automobile; in fact, taking the event as it is actually experienced, the sound is the automobile; sound and thought are simultaneous. But the sound is of course not really identical with the object itself, nor with the thought of it, but is merely the *sign* of the object, something causing me to think of it. The brain has combined the auditory reaction with a memory reaction to create the single impression experienced before we stop to analyze it. The "association" is more clearly in evidence when the sound arouses a definite memory picture of the object; clearly, the sound is one thing and the thought of its source is something else. With other sounds—other auditory reactions, the brain combines different memory activities, a process which occurs for all of the various sounds we are able to "recognize." Visual reactions, as will later be seen, are the richest of all in such associations; every visual reaction, in the adult at least, represents a combination of this kind.

A final word may be added to this brief sketch of the stimulus-response formula. Behavior considered simply as a series of reactions to external and internal stimuli would necessarily be a rather spasmodic or "jerky" affair were not these stimuli operative in a steadily flowing stream which would provide an adequate basis for the characteristic continuity and fluidity of concrete performance. Stimulation, especially of the internal

variety, is typically *persistent*, as when hunger, for example, sustains the organism in its exploration of the environment, or when curiosity drives the scientist through many months and obstacles in search of the answer to a problem. Stimulation is often referred to as a spur, goad, or prod to reaction; in very many instances it may better be regarded as a continuous inward pressure which, along with external stimulation, underlies the *sustained* activities—those exhibiting the quality of perseverance. The fact, further, that responses may themselves become stimuli contributes likewise to give smoothness and continuity to the curve of behavior. Muscles, for example, are equipped with sense organs which are stimulated by the movement of the muscle itself, and the stimulation thus internally furnished may arouse further movements without need of additional external stimulation, or at least with little beyond reenforcement from such sources. Skilled and well coordinated movements are carried on in this way by self-stimulation and are numerously exemplified in thoroughly practiced activities of the automatic type which require little conscious supervision. Such associated series of reactions are again seen in trains of thought, e.g., revery, in which each thought is, in a sense, the stimulus to the thought which follows, the series having been started, perhaps, by a sensory impression.

The combining or integrative operations of the nerve centers will be discussed at greater length and with the main emphasis on the psychological aspects of the process in the field of vision in a later chapter. Enough has been said in preface, it is hoped, to make clear what the term reaction means in psychology, and to provide a glimpse of the application of the concept to visual experience and ocular behavior.

## Chapter II

# FUNDAMENTALS OF BEHAVIOR

### THE ANATOMY AND PHYSIOLOGY OF REACTIONS

Psychology, as a brief examination of any general text will show, overlaps physiology to a considerable degree. Psychological reactions are reactions *of* physiological structures; consciousness itself rests upon and is an expression of physiological or neurological activity. Visual consciousness, or "vision" in its most familiar and concrete sense, is a result of cortical reaction as well as of receptor stimulation, and many of the facts of visual experience are intimately associated with physiological fact and theory.

Several of the structures underlying psychological reactions were briefly indicated in the preceding chapter. Behavior is universally an affair of stimulation, selection of response, and response; the corresponding structural basis consists, respectively, of receptors, centers of the central nervous system (the brain, brain stem and spinal cord), and effectors, which, e.g., the muscles, effect changes in the external world and in the relations of the parts of the body to it. To this scheme it requires only to add the connections between receptors and centers, between centers and effectors, and between the centers themselves, to complete in elementary outline the anatomy of reactions. At the receptor, which is in direct contact with the stimulus (ether waves, air waves, etc.), there arise physiological activities—the nerve impulses. The latter are conveyed to the centers—the "grey matter" of the brain or spinal cord—by sensory or afferent nerves. Issuing forth from the centers the impulses then flow over the motor or efferent nerves to the muscles, thus completing the circuit.

In the case of simple and immediate reactions the process may be thought of as involving a single receptor, a single center,

and a small muscle group. Reactions of the more complex type, including impressions from several receptors which must be correlated, and which entail conscious decision before the discharge of impulses to the muscles is released, require additional elements,—the "association" paths or tracts of the brain, which carry impulses from one portion of its grey matter to another. The central nervous system as a whole consists primarily of such tracts and centers (the white matter and the grey matter, respectively). The centers receive impulses from receptors or from other centers, and discharge them to effectors or to other centers. The tracts, wherever located, are simply connecting paths by which impulses flow from one center to another, on the way, generally, to the effectors.

A finger burn, let us say, results first in a sensation of pain; impulses pass over the pain nerves from the finger tips to the spinal cord at the level of the shoulder. Such nerves are called "peripheral" because they transport impulses from the periphery —i.e., points on or near the surface of the body· inward to the central nervous system. The impulses will then pass up the cord to the brain and to those areas of the grey matter of the brain whose activity arouses pain as a conscious event. Continuing the illustration: it then occurs to the sufferer to spread some sort of soothing application over the burn and he goes to the medicine cabinet to look for one. The impulses now pass from the centers basic to pain consciousness over association paths to those whose activity underlies "memory consciousness," —the thought of the best thing to do about a burn. Following this event the impulses flow to the "motor centers" of the brain which release the discharge for the muscle activity of walking to the cabinet. From the motor centers the impulses pass downward from the brain, through the spinal cord, issuing from its lower portion to flow over the nerves to the leg muscles.

While extremely complex in detail, the general outline of the functions of the nervous system may be stated in fairly simple form. All of the centers are engaged in the same work of receiving, directly or indirectly, the effects of stimulation from the receptors, and in distributing their discharges, directly or indirectly, to the effectors. The meaning of "indirectly" in the last statement is illustrated in the example just given; the activity of the "memory center" is finally traceable to the initial pain

stimulation, but is itself set up by impulses coming from the "pain centers" of the brain rather than from the receptors. Again, while impulses from the memory centers eventually account for the final behavior, they produce it only by way of the motor centers, which are in direct control of bodily movements. The reaction as a whole therefore has the form of a series of relays in which a number of centers participate. From a physiological viewpoint much of the difference between simple and complex behavior is the result of the number of such relays concerned. The brain is outstanding in the many relays it provides for with its various centers, specialized, as indicated, for different functions; in the large number of receptors from which it receives the effects of stimulation; and the many effectors over which it has control. The simpler centers of the brain stem and spinal cord are far more restricted in their connections on the afferent and efferent sides. A further reason for the brain's complexity lies in its function as a storage place for the structural changes by means of which the impressions of past stimulations are retained as memories (or rather the physical basis of memories), which help to determine the responses to present stimulation. And it is here that the reaction-correlating and reaction-coordinating operations mentioned in the preceding chapter go on.

Each receptor, then, is specialized to be sensitive to a particular type of stimulation, and as the consequence of such stimulation it discharges nerve impulses to the sensory nerves with which it is connected. These nerves, whether they extend, like cables, from the receptor to the central nervous system, or whether they travel, as tracts, within this system toward the brain, are simply transportation pathways over which the impulses flow to their various terminals in the centers. It is in the centers that the vital operations of switching and routing of impulses is managed, where the precisely organized outflow is coordinated which is finally to result in a precisely timed and patterned set or series of movements. The motor nerves which carry this discharge, to the tongue and lip muscles in speech or to the arm and finger muscles in a manual performance, are like the sensory nerves in being merely conductors, which now convey the results of the central operations to expression in the effectors. They deliver the centrally pre-

pared "orders" to the action structures. The latter are likewise specialized, the muscles to contract, the glands to secrete.

As previously mentioned, with the activity of the highest of the centers—those of the cortex of the cerebral hemispheres—is associated the phenomenon of consciousness. Viewing the centers solely as stations for the correlation and coordination of reactions, they might be said to differ from one another, the "lower" from the "higher," primarily in a quantitative way, the more complex ones being connected with a greater number and variety of sensory and motor channels. In relation to consciousness, on the other hand, they differ, in a sense, qualitatively, in that the activity of some is accompanied by awareness while that of others is not.

It is well for the student, in considering the structures of the nervous system, to keep the reaction formula clearly in mind, since, as Herrick has said,[1] no part of this system has any meaning apart from its relationship to the receptors and the organs of response. The function of every center, tract and nerve is concerned in some way with the general process of registering the effects of stimulation and of preparing and organizing effector activities designed to accomplish something of value in serving the needs of the organism. Even the most involved thought processes make use, in some form or other, of mental materials finally traceable to receptor stimulation, and more often than not lead, eventually, to some variety of concrete action. The procession of events in the nervous system must parallel, therefore, the course of behavior as a sensory-motor affair, and the architecture of the nervous system will be intelligible only in terms of conduct seen as a combination of reaction processes.

**The Elements of Structure.** As stated before, the individual reaction is behavior in its simplest form. Reactions are the elements of behavior in the sense that anything less than a complete stimulus-response unit is not behavior at all. Unless some sort of activity follows stimulation, there is nothing for psychology to study. While the reaction is functionally the element of behavior, its *structural* basis is not, however, an element of the nervous system, but requires a combination of elements.

These elements of structure are the *neurons* or nerve cells. The entire nervous system is built of these cells, is essentially a complex arrangement of neurons linked together in such a manner as to discharge the functions previously described. The parts of the neuron are represented in Figure 1. It consists of

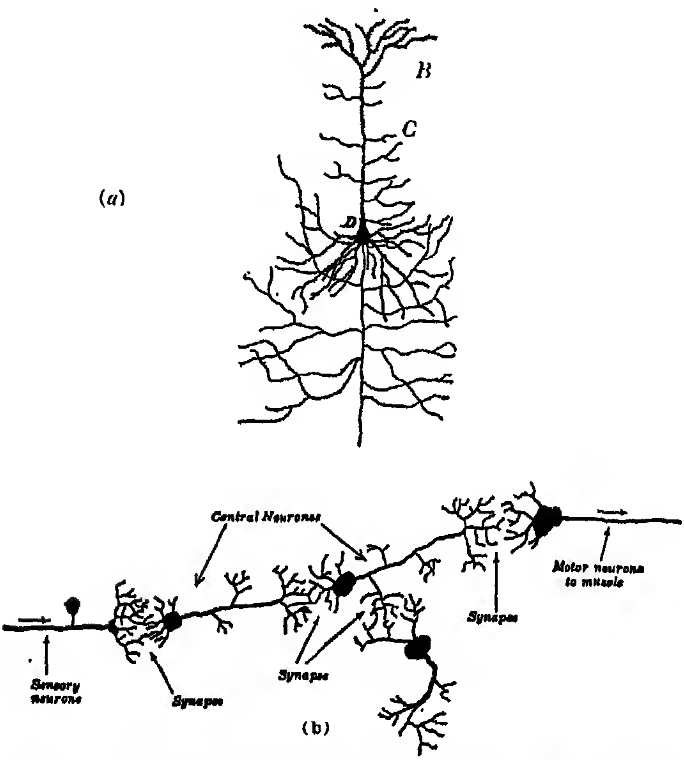


*Fig. 1.* (a) Neuron. A, dendrites; B, end-brush; C, axon; D, cell body. (b) Synoptic junctures. (Lower figure from Gates, Elementary Psychology, The Macmillan Co.)

the *cell body*, the *axon* or *fiber*, the *dendrites*, which receive impulses, and the *end-brush*, which discharges them. The juncture between end-brushes and dendrites, where the passage of impulses from one neuron to another takes place, is the *synapse*.

The centers, whose activities are so important in psychological reactions, are essentially groups of synaptic junctures, meeting places where the discharging ends of a few or many neurons

connect with the receiving ends of others, which in turn transmit them to the effectors or to other centers. The nerves and tracts earlier described are bundles composed of the axons or fibers of neurons, in which impulses are simply conducted from receptors to centers, between centers, and from centers to effectors. These fibers may be several feet long, as for example those which extend from the centers in the lower portion of the spinal cord to the muscles of the foot. Sketches of neurons often give a distorted impression of their proportions, the cell body being much too large and the fiber too short and thick. The fibers of the peripheral nervous system may be thought of as very long and very thin threads extending from the brain and spinal cord out to the sense organs or out to the muscles. The form of these structures is thus suggestive of their conductive function.

The simplest reaction would require, theoretically, a sensory neuron conducting impulses from a receptor and releasing them from its end-brush to the dendrites of a motor neuron, the latter carrying the excitation to a muscle or gland. Figure 2 repre-

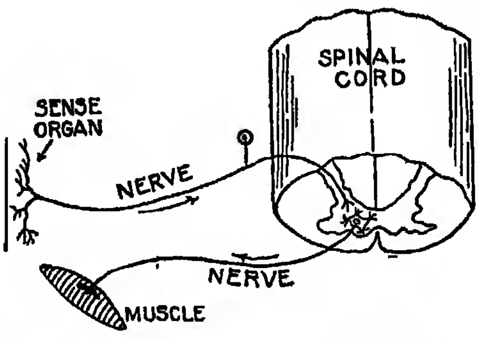


*Fig. 2.* The minimum essentials of a reaction: two neurons and one synapse. (From Gates, Elementary Psychology, The Macmillan Co.)

sents such an instance. It appears to be doubtful, however, whether the structural basis of any reaction is quite so elementary as this, the central connections for even the simpler reactions typically involving additional neurons interposed between the afferent and efferent paths (Figure 3), and the latter paths themselves consisting of at least several fibers. Usually many fibers, moreover, make entry at a synaptic juncture, and

they may have come from widely different parts of the nervous system. Single synapses, as Woodworth says, are rare if they occur at all; multiple connections are the rule. The over-

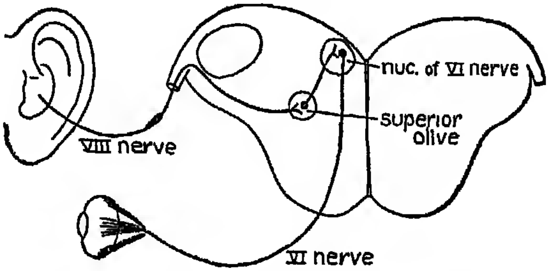


*Fig. 3.* One unit of the reflex mechanism by which the eye is turned in the direction of a sound. Auditory impulses from the ear travel over the 8th nerve to the superior olive (a center in the medulla). From here they are relayed to the nucleus of the 6th nerve. The final discharge results in contraction of the external rectus muscle of the eyeball, turning the latter toward the source of sound. (From Herrick, Introduction to Neurology, W. B. Saunders Co.)

simplified mechanism described above might stand, however, as a kind of symbol for the anatomical basis of even the more complex human reactions, for they entail only what might be termed numerical supplements to such a picture,—variations on the same theme.

This may be illustrated with an instance of behavior similar to one used previously and now described in terms of neuron "relays." The system concerned in such an act as removing the hand from a surface too warm for comfort will include first a group of sensory neurons whose fibers travel from the skin of the hand to the spinal cord. In the grey centers here these fibers will end at synapses where the impulses are relayed to another group of fibers which carry them to the centers for heat sensation in the cerebral cortex. Here another fiber group will pick them up and carry them to the cortical station where intentional movements are originated. A fourth relay will pass down from this point to spinal cord centers again, where the final relay will discharge to the arm muscles. Additional relays may be concerned in such acts, but the above covers the fundamental ones.

The structure of the centers likewise suggests their function. A meeting place of the discharging ends of many neurons and

the receiving ends of many others is obviously designed for the process of switching or routing impulses over any one or several outgoing paths just as a large railway terminal is a converging point where lines from many sources make connections. The centers of the human cerebral hemispheres are said to contain over 9,000 million neurons, each connected by fibers with numerous other centers, in the brain and elsewhere. It is the distributive operations of these junction points which subserve the correlation of sensory impressions, the arousal of memories related to these impressions, and the integration of effective behavior.

The centers of the cerebral cortex--the grey matter of the brain, compose a thin layer of tissue, varying in thickness from 2 to 4 millimeters, spread over the surface of the hemispheres. Other "sub-cortical" centers are located below the cortex, but a very large part of the brain beneath the cortex appears white in cross-section and consists of bundles of fibers, some of which originate in the cortex itself, others in subcortical centers. Many of them pass between different areas of the cortex, all parts of which are connected, directly or indirectly, with all

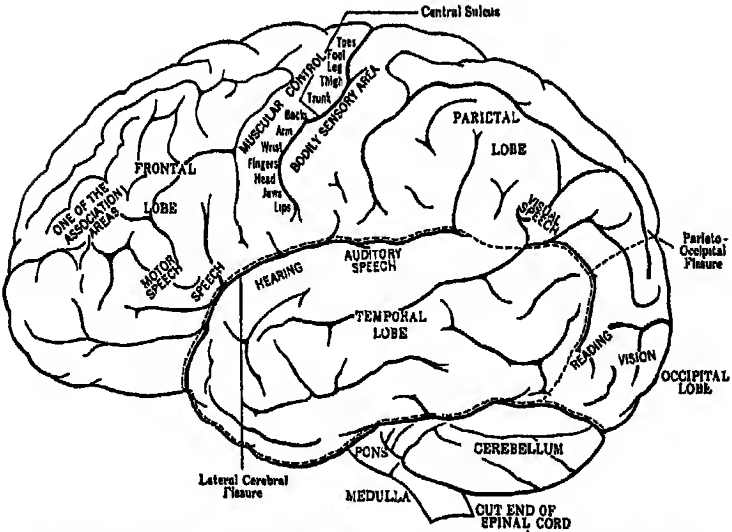


*Fig. 4.* Diagram of the left side of the cerebral cortex, showing the location of some of the sensory and motor functions. (Reprinted by permission from "Psychology" by Boring, Langfeld and Weld, published by John Wiley and Sons, Inc.)

other parts. They make up the greater portion of the total mass of the hemispheres, symbolizing the importance of the relaying of impulses between the various stations.

It will be observed from Figure 4 that there exists a division of labor, or specialization of function within the cortex, different areas serving such different processes as body sensations, control of the movement of body and speech muscles, vision and hearing, the understanding of spoken and written language, etc. Aside from the more or less direct cortical connections with the receptors and effectors (the sensory and motor areas) large parts of the cortex consist of "association" areas which are the probable seat of memory. These areas are greatly enlarged in the human brain as compared with that of the anthropoid apes, whereas the sensory and motor areas of the latter are more comparable to those of man. Our knowledge of the cortical location of different mental functions has been worked out by several methods, among them the correlation of accidental injuries to the brain and of destruction of tissue owing to disease with the resultant disorders of behavior; the deliberate experimental destruction of portions of the brain in the higher apes; and the electrical stimulation of the exposed brain, which in a few cases has been possible in man.

**The Nerve Impulse.** A few words may be said at this point regarding the nature of the "impulses" so often referred to in the preceding pages. The term itself suggests, not a steady flow or movement, but a spasmodic, rhythmical action. The nerve "current," like the blood, is transmitted in a series of pulsations, though in much more rapid succession. The nature of these pulsations is complex and the details are not necessary to the purposes of visual psychology. It will suffice to say that the discharge within the individual neuron appears to be a "depolarization" phenomenon with chemical as well as electrical aspects; oxygen is consumed, carbon dioxide and heat released; the wave of activity travels about 100 yards per second. The energy of discharge is supplied by the neuron's own metabolism; it is not furnished by stimulation or by the preceding neuron in the relay. What is transferred from one neuron to another is the excitation (trigger action) for a wave of self-generated activity traveling along the course of the fiber. It is only in this sense that impulses may be said to "travel" from one neuron

to another. Two other points may be added: the discharge of the neuron involves all of its resident energy; if it discharges at all it discharges with its maximum capacity (the all or none law); a strong excitation accomplishes no more than a weak one, any more than pulling a gun trigger harder will increase the force of the explosion. Further, the discharge temporarily exhausts the neuron; immediately afterward it will not respond to any excitation, however strong (absolute refractory phase). Following this there is a period of slow recovery of excitability (relative refractory phase) when a strong stimulus will produce a discharge while a weaker one will not. Finally the neuron reaches its normal condition of excitability.[2, 3]

These physiological facts are closely related to an aspect of visual experience. As the intensity of illumination,—of retinal stimulation, increases, the visual image becomes brighter. The basis of this phenomenon centers in the rate of impulse discharges per second excited in the fibers. According to the all or none law a stronger stimulus does not increase the strength of discharge in the fiber, but so far as it can excite the impulse earlier during the fiber's relative refractory phase it will excite it more frequently and thus increase its rate of discharge. The stronger the light stimulus the sooner during the recovery interval the fiber will discharge again, and thus a ratio between strength and rate will obtain. The upper limit of this rate will be set by the length of the period immediately after discharge when no stimulus, however strong, will arouse the fiber. An additional factor here, moreover, will be the *number* of fibers carrying impulses to the visual area of the brain. Assuming that the retinal receptors differ somewhat in sensitivity (threshold), that some require more intense stimulation than others, a stronger stimulation will arouse impulses in more receptors and thus more fibers, as well as more impulses per second in each one.[4]

**The Synapse.** The juncture between neurons is an important item in psychological theory. Physiologists are not yet decided as to the detailed structural character of the synapse. The important facts, at this point, are that there appears to be some degree of physical separation of the fibers at these junctures, the cellular protoplasm not being continuous; that the rate of travel of the impulses is reduced as they cross the

synapse, suggesting a lesser permeability at these points; and that a kind of valve action is attributed to the synapse, permitting impulses to flow only in one direction,—from the end-brushes of one fiber to the dendrites of the next. The fibers themselves may conduct in either direction. Coupled with the arrangement of the neurons themselves this last rule of "one-way traffic" is related to the fact that behavior is uni-directional, that reactions are receptor-to-effector movements.

Much of the psychological doctrine regarding the learning process, the development of new reactions through the formation of new paths between receptors and effectors, and the increased facility of reactions as the result of exercise, revolves about processes at the synapse. The fact that the synapse is a point from which conduction over many paths is possible, and that these junctures are more susceptible to the action of drugs and to fatigue, suggests that the processes here may be the seat of the *modifications* of structure underlying the changes in reaction called learning. The greater readiness and facility of practiced reactions, for example, may be attributed to increased permeability at the synapses, owing to the repeated flow of impulses across them, whereby subsequent streams of impulses encounter less resistance to their passage. Such increased permeability might result from a changed alignment of the molecular structure in the membranes at these places, facilitating the transmission process. Possibilities in the way of chemical conditions have been suggested whereby an actual movement of the neural filaments toward each other could occur, thus improving conductance.[9] The increasing ease of practiced performances, motor and mental, appears to be in part the result of such increased synaptic permeability. Individual differences in ability to fix and retain memory material may be the expression of inherent differences in neural tissue quality relative to the establishing and the retention of modifications. The general decline of such abilities with old age may perhaps be explained in similar terms. These concepts can be applied to such peculiar phenomena as the occasional cases of loss of memory resulting from shock, in terms of the derangement or "jarring loose" of the delicate linkages established at the synapses.

## TYPES OF REACTION

There are a number of ways in which reactions may be classified. They might be grouped, for example, by reference to the organ of response principally involved, as muscular, glandular, or cortical cell ("mental") reactions; or in terms of levels of complexity; or on the basis of the presence or absence of the "will" in their occurrence; or as inborn and acquired. Considering the enormous variety and complexity of human behavior, any such classification which helps to order and systematize one's way of thinking of behavior is of value. A few suggestions in this direction may therefore be included here which bear on those types of reaction which are central in visual psychology.

**The Reflexes.** Among the simplest of human reactions are the reflexes. These responses do not have to be learned, are automatic (do not require volition or "willing"), are definite and precise, and follow immediately upon stimulation. They involve no anticipation or foresight on the part of the individual as to what response is to follow stimulation.[6] Examples of reflexes would include, in the sphere of visual reactions, the pupillary or light reflex (constriction and dilatation of the pupil in response to changes of illumination); the rotation of the eyes toward an object located anywhere outside of the center of the field; the following of such an object, once fixated, if it should move; the convergence or turning inward of the two eyes toward each other as a fixated object draws nearer or as fixation shifts from a farther object to a nearer one; accommodation, or the change in form of the lens of the eye designed to place or keep the image of an object "in focus" on the retina as its distance changes; the protective blinking of the eyelid following contact of an irritant with the cornea or external membrane of the eyeball; the periodic blinking which normally occurs at intervals to bathe the exposed external membranes. Other reflexes are sneezing, coughing and hiccoughing; shivering, trembling and starting (to a sudden sound); blushing, paling, laughing, smiling and scowling; sucking, swallowing and vomiting.

It will be recognized at once that many of these reactions may be inhibited or modified by voluntary effort, and that many of the muscle movements involved in them may be initiated at

will. Classifications of the reflexes has been outlined in terms of their degree of susceptibility to voluntary influence.[7] Obviously one can "deliberately" wink, rotate the eyes, converge, start, smile, cough, scowl, etc. Such reactions, however, are not reflexes. They represent a different type of reaction, the voluntary type, and the instances mentioned simply show that a given act may be produced in two different ways. The neural pathways concerned, for example, in reflex and voluntary rolling of the eyes are to a considerable degree separate, though they finally take a common course to the same muscles. In

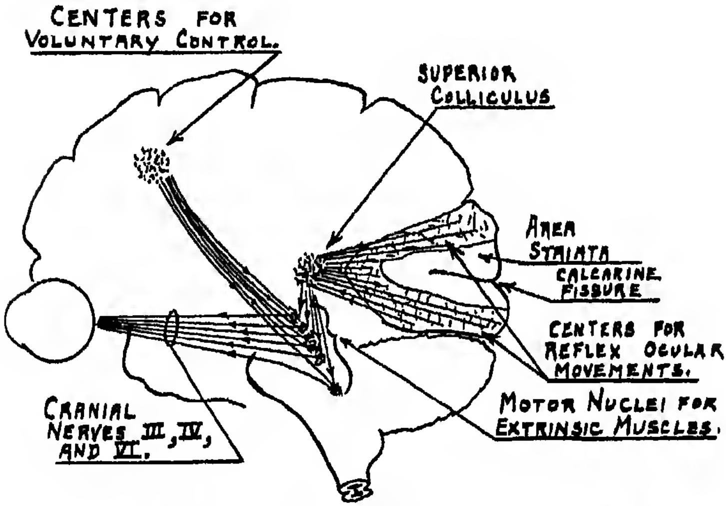


*Fig. 5.* Lateral view of the cerebrum, diagrammed as though transparent, showing the location of the centers for voluntary and reflex control of ocular movements. These centers are bilateral and are in the cortex, i. e., in the surface of the hemispheres.

these cases voluntary control is superposed upon the organs of response involved in the reflex. Figure 5 shows the anatomical basis of such control. A difference between the two kinds of reaction is usually apparent in experience; reflex (i.e., "true") smiling and laughing, for example, "feel" quite unlike the deliberate smile and the forced laugh, though outwardly they may be made very nearly indistinguishable (with a little practice!). In other cases, as sneezing, while the act is not under voluntary control in its initiation, it may be restrained in various degrees, including complete inhibition provided

stimulation is not too intense. Reactions exhibiting superposed voluntary control, and especially the voluntary initiation of otherwise reflex movements, may serve as illustrations of the statement that the higher forms of behavior in general express themselves only through the agency of the more fundamental reflex organizations.[8]

Reflex reactions differ markedly in complexity; blinking, for example, as compared with emotional or sexual reactions; they differ also, as previously noted, in docility relative to voluntary influences. A third difference lies in the requirements of reflex action in regard to the presence or absence of consciousness. This is the distinction between physiological and "sensation" reflexes, or, to introduce the terms to be used hereafter,—between physical reflexes and "psycho-reflexes." Visceral activities in general fall within the former category, i.e., the reflexes associated with the functioning of the internal organs, such as breathing. An example of a visual reflex of the physical type is the photo-pupillary or light reflex. The pupil will constrict in response to an increase in illumination even though the individual himself is unconscious. The reflex does not require that the stimulus register any change in consciousness; no sensation is necessary. Correspondingly the neuron path *basic* to this reflex does not pass through the centers of the cortex, whose activity is the seat of conscious impressions. Ordinarily, of course, we *are* aware of the stimulation—the change in illumination; the impulses set up by stimulation therefore do flow through the cortex. The distinction between physical and psycho-reflexes rests upon the fact that in the former case sensation, or the entry of the effects of stimulation into consciousness, when this occurs, is not *essential* to the response. Awareness of the increase in illumination, that is, is not necessary to the light reflex; it is usually present, but is incidental.

The psycho-reflexes, on the other hand, do require registration of the stimulus in consciousness. The major visual reflexes of version, accommodation and convergence, come under this heading.[9] In rotation of the eyes toward a light source, for example, there must be more than stimulation of the retina; awareness or "perception" of the object, together with a certain degree of attention, or interest in it, is essential to the arousal

of the muscular adjustments. If the cortex is the organ of consciousness it follows that the activity of this highest of centers is required for these reflexes. All retinal reflexes, excepting that of the pupil to light, are dependent in this way upon the operation of those areas of the cortex which underlie visual consciousness.[10] Certain important features of the function of the psychic factor in these reflexes will be dealt with in the chapter on the relations between attention and vision.

While consciousness is thus essential to the psycho-reflexes, volition is not. Once the object is perceived, the muscular adjustments of ocular rotation and focussing take place automatically. The nerve centers whose discharge of impulses subserve the innervation and coordination of these adjustments are not those active in deliberately willed movements, such, for example, as "gesturing" with the eyes or "looking cross-eyed." Awareness of the sensory impression and the arousal of some degree of interest in it, are the mind's only contribution to the essentials of these reactions; the responses are as completely self-governing as a cough or a sneeze. Normally we are no more conscious of the *acts* of convergence and accommodation than we are of pupillary changes.

**Voluntary Acts.** Reflex reactions are seen in purest form in infancy. Voluntary control is little by little superposed. All voluntary acts are consciously performed and therefore involve brain activity. Introspectively a voluntary act is easily distinguished from a reflex. In the former we are conscious of willing; there is a moment in which we are aware of an *intention* just preceding the occurrence of the intended act. This experience is especially clear during the learning of new performances, in which the intention is accompanied by some sort of an idea, more or less defined, of the action to be achieved. A reflex act, in contrast, and so far as we are conscious of it at all, has a quite different feeling about it. It exhibits an impulsion of its own, a "will," as it were, which is not *our* will. The impression is vivid in acts like coughing, sneezing, and vomiting, especially if any attempt is made to inhibit them. The separateness of the two types of behavior is seen in cases in which voluntary control of a muscle group is absent owing to brain injury, leaving only the reflex centers intact. The individual may be unable to move his facial muscles at will, yet

they spring instantly into a smile when a humorous remark is made. He may be unable to close his eyes intentionally, but they close at once when a threatening object approaches. Again, he may be unable to voluntarily move his eyes, which, however, rotate effectively in following a moving object, once it has been fixated.

Performances originally voluntary in almost every detail may with practice become to a very marked degree unconscious and involuntary. Such automatic acts can often be distinguished from reflexes only by their developmental history. They are illustrated in dozens of brief, habitual acts of the daily routine; in dressing and undressing; in the machine-like motions of an experienced driver as he winds through traffic while absorbed in conversation or reverie, and as he instantly jams down his brake pedal when a red light appears suddenly. Probably the majority of our actions are composites of voluntary and automatic elements in which the former exercise a merely supervisory control over the latter. This feature of behavior will be noted again later in the case of the ocular movements.

Generally it may be said that, except in the initial stages of learning a new performance, so called voluntary activity is largely an affair of the releasing of systems of automatic, reflex-like movements. In carrying on the active part of a conversation, for example, we are primarily conscious of the meanings we wish to express and of the manner of our expression, and little if at all aware of the individual tongue and lip movements which vocalize those meanings. Our thoughts, once selected, formulated, and shaped into the general pattern of a phrase, are automatically translated into the proper muscle contractions. The larger units of the act are those which call for attention and decision; the elements take care of themselves. A similar description would apply to almost any well developed motor sequence, in athletics, typing, piano playing, etc. Attention is centered principally on the end-results to be achieved, not on the means of achievement—the detailed innervation and control of the muscles. Under the influence of the formulated aim, the "mental set," the neuro-muscular patterns automatically respond, and often, curiously enough, with better coordination the less conscious we are of them. The function of the "higher," voluntary centers of the brain

is coming to be seen as largely the general supervision, releasing and controlling of mechanically or semi-mechanically operating reaction systems.[11]

## THE ASSOCIATION OF REACTIONS

**General Phenomena.** The preceding description of reaction types has emphasized primarily the reflexes because of their great importance in connection with vision. Such reactions were stated to be innate, meaning that their underlying neural organization is largely the result of the natural growth processes determined by heredity. They represent behavior of the "instinctive" kind. It is often extremely difficult to discover, however, to just what degree a *developed* adult reaction has been modified by experience, even though pure of such influences at its first occurrence, and this issue is involved in any consideration of the ocular reflexes. On the *sensory* side, however, visual reactions are enormously overlaid by experience—the persisting and associated effects of previous reactions. We therefore turn to a brief study of the manner in which this process of modification and supplementing of reactions takes place.

The foregoing consideration of the reflexes furnishes a good point of departure toward the modern doctrine of learning, since the cornerstone of this doctrine was built from experiments on the modification of reflexes. The latter will now be thought of as a specific form of response occurring immediately, automatically and regularly upon presentation of the proper stimulus, and grounded upon a neuron relay consisting of a receptor, an afferent path, one or more centers, and an efferent path leading to a muscle or a gland. This account implies the "pure" reflex, unmodified or complicated in any important way by the effects of experience. The question now arising is: under what conditions are *new* paths formed between receptors and effectors; or, in other words, how are new reactions established; how does the individual *learn*? Once a new reaction occurs, once the form of its path is laid down, repetition, as was noted above, renders it more facile by making its path more permeable, but the query remains as to how the form of the reaction was at the outset prescribed.

The answer to this question may be introduced with a description of one of the most famous experiments in the history

of science. Around the beginning of the present century the Russian physiologist Pavlov disclosed some facts about the reflexes which have since been endlessly described in texts of physiology and psychology, and on the basis of which whole systems of psychology have been erected. Pavlov observed that the flow of saliva from a dog's mouth, which he was able to measure by piping it out of a tube inserted through an incision in the animal's cheek, was stimulated not only when food was present in the mouth, but also by the sight of food, or of the dish on which it was customarily brought, or by the sight or sound of the feeder. The same phenomenon is exhibited, of course, by everyone whose mouth has watered at the sight of food when hungry, or by the mention of a favorite food. Salivation in response to food in the mouth is the true or natural reflex, in this case, but salivation in response to the sight of food must be an *acquired* reaction, since when the young animal sees meat for the first time no secretion results. The reflex has become attached, somehow, to various other stimuli, visual, auditory, etc., usually present when food was given. Any one of the incidental conditions accompanying the natural stimulus to a salivary flow may acquire the power to evoke this response. When, accordingly, the reflex is aroused by any of these conditions, it is called the *conditioned* reflex.

Pavlov then decided to study the matter further by selecting and controlling these accompanying stimuli himself. He found, for example, that when food was presented repeatedly with the sound of a bell or with a flash of light these latter stimuli would by themselves produce a secretion, though not so much as the food. The response could in this way be attached to a variety of stimuli, such as the sound of a metronome, a tuning-fork or a horn; luminous figures of different forms; heat and touch; chemical odors. By presenting food with one stimulus and by withholding it with another, similar but different in some way, the reflex could be "conditioned" to the one and inhibited in relation to the other. Thus pressure on one part of the dog's body would lead to a flow of saliva, while on an adjacent part of the skin it produced no flow, since no food accompanied the latter stimulation during the training period.

Some interesting results followed the use of this method with visual and auditory stimuli. Visual forms were presented on a

screen before the dog, consisting of images of various colors, intensities, sizes, etc. It was discovered that the animal could distinguish between lights of different intensities but not of different colors; color vision in the dog appears to be lacking.[12] Form vision, however, was found to be rather highly developed. A luminous circle was distinguished from an ellipse of the same brightness. Beginning with ellipses whose axes were in a 1:2 ratio, the animal was able to discriminate these from circles through a series in which the ellipses approached more and more to the circular, failing only when the axis was 8:9. Different shades of grey were also distinguished, a high degree of brightness discrimination being manifested. A surprising capacity for auditory discrimination was also discovered, the animal being highly sensitive to differences in the pitch, rhythm and intensity of sounds. 100 beats per minute of a metronome were distinguished from 95 per minute. Differences in the intensities of two sounds discernible with difficulty by the human ear were detected by the dog. Pitch differences of only 12 d.v. per second were discriminated. The method here was the same as that used in the case of vision, one stimulus being reenforced by presentation of food, while the other was employed without such reenforcement.

Pavlov centered his work primarily on the salivary reflex, but other investigators extended the method to other types of response. As a few examples, the eyelid and pupillary reflexes were conditioned to bell stimulation; likewise the knee-jerk. Conditioned defense reactions, such as drawing back a limb in response to an auditory stimulus, have been established, the original training in this case consisting of the presentation of a bell or buzzer sound along with an electric shock to the hand or paw. A fear reaction evoked originally by a loud sound (in an infant) was transferred after brief training to the sight of a rat, no fear of which was manifested at the outset.[13] It has been found possible, moreover, to use a response, itself conditioned, as the basis for further conditioning. A response, for example, which has been attached to a visual or a tactual stimulus may be associated with an auditory stimulus by presenting the latter along with the visual or the tactual agent. Thus more than one "order" of conditioning is possible.

A few other fundamental properties of the conditioning process may be indicated. The new stimulus must precede or at least accompany the natural or unconditioned stimulus if it is to become potent as an excitant of the reflex. If, i.e., the bell or light follows the feeding, it will not become effective by itself, however much repeated. The conditioned response, again, is not as vigorous as that made to the natural stimulus, and declines, moreover, finally to extinction if not accompanied at intervals by the natural stimulus. This gradual elimination of the reaction appears to be similar to or identical with the phenomenon of "negative adaptation":—the decline and disappearance of any useless reaction. A cat will cease to come when called if never petted or fed; the salivary secretion is pointless behavior if no food is forthcoming; we "get used" to many originally distracting sounds and cease to be bothered by them.

**Experiments on Conditioning; Motor Reactions.** A few examples of experimental conditioning may be described. Many of these are highly artificial and demonstrate, by this very fact, that almost any extraneous stimulus, by its mere contiguity in time with the natural excitant, will become capable of arousing the response. Cason[14] conditioned the wink reflex (corneal reflex) to a sound stimulus. Normal closure of the lid is induced by an intense light, irritation of the cornea, contact with the lashes, or a sudden sound. The wink was experimentally elicited by electrical stimulation, an electrode being placed just under the right eye of the subject, probably giving direct stimulation to the facial nerve fibers controlling lid closure. The conditioning stimulus was a sharp sound which, however, was not sufficiently intense to evoke the lid reflex at the outset of the experiment. The shock and sound were given simultaneously from 500-3,000 times at intervals of 3 to 6 seconds, the combined stimulations being supplied a number of times, then the shock stimulus cut to disclose whether conditioning to the sound had been established. The conditioned response finally developed could be aroused considerably faster than was possible by *voluntary* control; the subjects, moreover, reported that they were not aware of the wink until after its occurrence. The volitional factor appears, therefore, to have been absent; a direct connection was established between the

auditory receptor and the lid muscles, not involving the voluntary centers of the cortex.

Cason also succeeded in conditioning a reflex not subject to voluntary control—the light reflex of the pupil.[15] The natural stimulus here is a change in light intensity; the conditioned stimulus was the sound of an electric bell. At the beginning the bell was found to dilate the pupil in every case. A marked change in the pupillary diameter was then brought about by altering the illumination, the bell stimulus being given while this change was taking place. The pupil was then measured with and without the bell, and the effects of conditioning thus determined. By supplying the bell stimulus during dilatation (the light being turned off), and also during contraction (the light being turned on), both types of pupillary change were conditioned. Conditioned dilatation following the bell was found to be greater in degree than that effected in this way before the training. 400 repetitions constituted the training period. In one case, for example, the bell dilated the pupil 3.5 tenths of a millimeter before training, and contracted it 1.7 tenths after training. Cason succeeded in establishing the conditioned response in all of his 13 subjects. Since, as stated, the pupil is not subject to voluntary control, it appears that genuine conditioning was achieved. Introspective reports showed that the subjects were not thinking of either contraction or dilatation at the time it occurred. The conditioned change in the size of the pupil was small but definite.

Another study of the light reflex demonstrated that what appears to be true voluntary control over this response may be developed by appropriate conditioning technique. Hudgins'[16] experiment confirmed the work of Cason and demonstrated that the conditioned pupillary response to an auditory stimulus may be the basis of a still "higher" order of conditioning. The essentials of the apparatus included a light source with optical means of directing the light into the eye of the observer, and a telescope equipped with a micrometric device for measuring the diameter of the pupil. The micrometer attachment contained two parallel hairs which could be brought tangent to either side of the pupil during measurement, the diameter then being read from a scale in tenths of a millimeter.

The procedure illustrates the "stimulus-reduction" formula in that the reflex was first conditioned to a complex of stimuli which were then one by one eliminated until only the volitional factor remained. The light reflex was first "connected," as in Cason's experiment, to the bell stimulus. The word "contract" was then given by the experimenter, following which the subject pressed on a device which closed the circuits for the bell and light stimuli. The verbal command in this way became one of the conditioning stimuli, along with the bell and the hand movement. (The possibility of developing one conditioned response on the basis of another was mentioned above.) The next step was the elimination of the bell and the hand movement, leaving only the verbal command of the experimenter. Then the subject *himself* gave this command, first aloud, then in a whisper, then silently. He was now supplying the stimulus for the pupillary change; he had, in other words, obtained voluntary control over it by a process of transfer and reduction of stimuli, each of which in turn became linked with the reflex. In two of the fourteen subjects the ability was still present two weeks later without training in the interval.

Since it is known that pupillary changes accompany accommodation and convergence an attempt was made to keep fixation constant during the experiment. Tests showed that the conditioned pupillary changes were three times as great as those associated with shifts of accommodation and convergence. Unintentional shifts of fixation thus cannot account for the results, which demonstrate that smooth muscle activity may be conditioned to self-induced stimulation. Ten of the fourteen subjects did not know that their pupil reflexes were being modified; specific volition thus appears to have been absent. The experimenter offers the hypothesis that "so-called" voluntary behavior may be simply a self-excited conditioned response.

The study of such artificial cases under controlled laboratory conditions may cause the student to lose sight of the commonness and familiarity of the essential phenomenon. A farmer is "conditioning" his horse to move at "Giddap" when he accompanies this command by a flick of the whip. Innumerable instances might be taken from everyday life. A person made seasick by the roll of a boat may later experience qualms in response to the characteristic odor of a ship. Developing a

liking for a certain individual, we may find ourselves "drawn" to an unknown person who merely resembles him in some feature. The sight of a cut lemon will arouse a salivary flow in a person who has sucked one. Music heard at a funeral may later arouse the depressed feelings originally called forth by the funeral itself. It has surely been known since prehistoric times, as Knight Dunlap suggests, that animals learn to come for food when called because the call is given at feeding time. The conditioning experiments simply placed a fact of common knowledge on a scientific basis.

**The Physiology of Conditioning.** The conclusion which may be drawn from the foregoing observations is that when two originally independent reactions occur together or in the proper succession a certain number of times, the stimulus for one reaction becomes effective in evoking the other reaction as well. The question now arises as to the nature of the neural processes underlying this association of reactions. If sensory, central, and motor fibers are the structural elements of reactions, and if a sensory-motor flow of nerve impulses over these structures is the functional basis of psychological events, it is necessary to

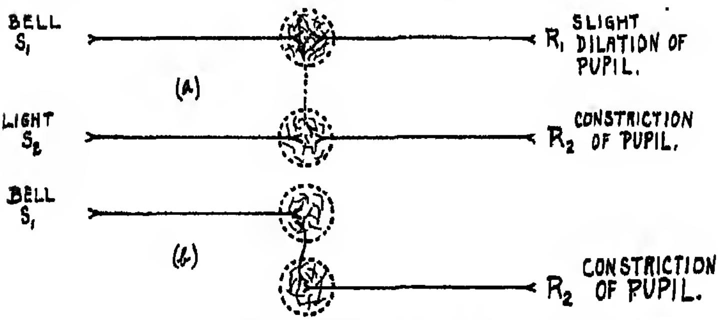


*Fig. 6.* (a) Symbolizes the neural situation before conditioning is established. The two reaction systems are anatomically connected at the centers but functionally independent. When both stimuli occur together pupillary constriction is dominant. In (b) the interconnecting path between auditory and constrictor centers has become active, and constriction follows the bell stimulus.

believe that in the conditioned light reflex, for example, some of the end-brushes of the axons of the auditory nerve fibers must have been brought into functional connection with dendrites of the fibers leading to the muscles of the iris.[17] This

connection would have to be established at the *centers*. A new pathway, that is, must become functional between the centers for hearing and those controlling the light reflex, just as a similar path would be necessary, in Pavlov's experiment, to carry impulses from the hearing center to the center discharging to the salivary glands. Figure 6 illustrates the character of such a formation.

There is evidence that all parts of the nervous system are anatomically connected, directly or indirectly, with all other parts. Fiber paths existed, that is, between the centers concerned in the above experiments before the latter were begun. These paths then became functionally active during the training period. Here the concept of "drainage" is involved. The afferent impulses from the auditory receptors, flowing while other impulses are independently discharging from another center to the salivary glands, "drain" over interconnecting fibers into this center, thereby increasing the permeability of the new path (interconnecting) for a later discharge over the same route.[18] With sufficient exercise the auditory flow over this drainage channel becomes strong enough to arouse the salivary secretion in the absence of the normal stimulus for that reaction. There is a tendency, it appears, for an established neural pathway, when active, to divert some of the impulses flowing in other active pathways from their normal courses into its own channels. The "normal course" of the auditory impulses in Pavlov's experiment led primarily to the muscles erecting the ears and turning the head. In Cason's experiment, as he suggests, the natural response to the bell, in addition to its slight dilating effect on the pupils, probably included alterations in heart-beat, breathing, etc.

The drainage doctrine appears to be a valid deduction from the facts of conditioning and the known structure of the nervous system. Its place will be seen again in the section following.

**The Sensory Aspect of Conditioning.** If the term response is applied to any activity aroused by nerve impulses following their flow over the sensory neurons, such conscious impressions as sights, sounds and pressures are to be considered as responses, even though they may not express in any externally observable behavior. These sensory reactions, as was earlier mentioned, become richly overlaid by the persisting effects of previous

reactions, i.e., by experience. The mechanism by which such supplementation is effected will be briefly indicated here and discussed somewhat more at length in the chapter on Perception.

The learning process is the same on its sensory side as on its motor side. There is no essential difference between the process basic to the above-described modification of reflexes and that underlying the formation of "mental associations." Thoughts are "conditioned" as well as reflexes. When a child, for example, is shown a picture of a dog and at the same time hears the corresponding spoken word, the visual and auditory reactions become linked in the same manner as the visual and glandular, auditory and glandular, auditory and

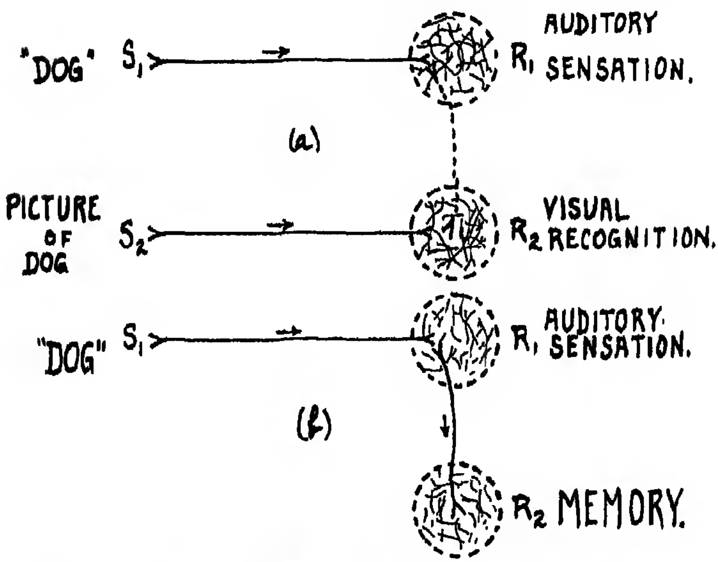


*Fig. 7.* The diagram represents the theoretical neural basis of the formation of associated memories. In (a) conscious reactions occur in the centers for hearing and seeing. A fiber path between the centers is exercised. In (b) this path has become established. Impulses flowing into the visual center from the auditory center arouse a more feeble activity than that resulting from retinal stimulation. This activity is experienced as a memory of the earlier visual impression.

motor, etc., reactions previously described. Pathways in this instance will become functionally active between the visual and auditory centers of the brain. Later, hearing of the word "dog" will arouse, not the *sight* of the picture, of course, but

a feebler reaction called a memory (Fig. 7); conditioned responses, it will be recalled, are typically weaker than those made to the natural stimulus (the picture itself, or rather the resultant retinal stimulation, being here the "natural" agent). The impulses arousing the memory response in the child's visual centers have come, not from its retina but from the associated auditory centers.[19]

Such a memory may therefore be regarded as a modified sensory response evoked by way of other receptor channels. The child, in the above example, is now said to *understand* the spoken word "dog"; he is conscious of its meaning in visual terms. In a similar fashion he learns to associate this meaning with the sight of the printed word, and is then said to have learned how to "read" it, the visual stimulus or word here being comparable to the bell stimulus in Pavlov's experiment. The process whereby the memories of sensory impressions become associated with (or conditioned to) other sensory impressions (or stimuli) is the development of *perception*. All adult visual reactions, on the sensory side, are perceptual in character. In summary, it should be noted that the main difference between associative memory and conditioned movements and secretions lies in the organs of response concerned. Muscles and glands are the essential terminal structures in the one case; cortical brain cells in the other. The fundamental mechanism, however, is the same.

This review of elemental principles may be concluded with a few words concerning the reaction viewpoint as applied to conscious events. The latter, along with muscle movements, are the central studies of visual psychology. Obviously, a muscle contraction is an activity which simply expresses the operation of the structure; the contraction is the structure functioning. No one thinks of the contractions as somehow stored up in the muscles, awaiting release. A comparable notion is not infrequently encountered, however, in the case of mental events. Thoughts, for example, are sometimes referred to as though they literally exist, as thoughts, somewhere in the mind, when their owner is not aware of them. They may be conscious one moment and "unconscious" the next, passing, when they

"leave the mind," to some sort of psychic reservoir where they reside as free-floating bits of mental stuff, awaiting "recollection."

If the student has understood the reaction principle he will perceive the fallacy of this view. Thoughts are not *things* but reactions—*activities*. They are generated by a flow of impulses through the neural filaments composing the cortical grey matter. They exist, as thoughts, only so long as this flow continues; when it ceases they also cease. They do not "go" anywhere, or rather they "go out" as a light goes out when current stops flowing over the wires. Nothing remains but the anatomical basis of the mental event, i.e., the inactive neural structures whose previous activity created the specific content of consciousness. A visual memory image, in this respect, is to be regarded in the same manner as a visual sensory impression. The latter is the result of a stream of impulses, originating at the retina, through the pathways of the visual areas of the cortex. The sense impression exists only for the duration of this flow. When the light stimulus is withdrawn the stream ceases and the sensation with it. Sensations are surely not "stored" in the eye or in the mind, awaiting future revival. The same conception applies to the weaker, centrally stimulated arousal of cortical structures in the process of recollection. It has been suggested that, since these experiences are activities rather than objects, such terms as "perceiving" and "remembering," which suggest actions, are more valid and less misleading than nouns like "perception" and "memory."

## Chapter III

# THE VISUAL REACTION SYSTEM

The preceding chapter attempted a short outline of some of the general elementals of behavior. The present one advances, on this basis, more closely to the main theme—the psychological aspects of the optical reactions. While a considerable amount of the material at this point is still concerned with the physiological foundations of these reactions, it is believed that this ground work is definitely essential to a thorough comprehension of visual phenomena; that the physiology and psychology of vision are inseparably linked. Psychological reactions, as stated before, are expressions of the activities of structures, and many of these expressions can be well understood only in terms of the processes underlying them. Later chapters will deal much more exclusively with a descriptive psychological account of visual experience, with less space devoted to neural correlates. Such restriction, however, reflects mainly the incompleteness of present knowledge in regard to the physiological basis of the "higher mental processes" so far as they relate to vision. Certainly such knowledge would contribute as much enlightenment in the sphere of optics as it has in other fields of psychology, when available. The amount of time devoted in the pages following to the processes of the visual nervous system represents, however, only as much as seems necessary to the brief and elementary survey of visual psychology intended in this text. For any further detail the student is referred to books on physiological optics.

All reactions begin, to repeat once more, with the stimulation of receptors, and take the form of conscious events and of muscle movements. Consideration of the glandular responses related to the ocular mechanism may be omitted from this study. The visual reaction system will be regarded, accordingly, in

terms of the stimulation of the retina, the resultant conscious impressions, and the movements of the ocular muscles. The conscious impressions, moreover, will be the immediate consequences of brain activity, itself aroused by impulses from the retina. The movements must be coordinated and made "adaptive" by centers discharging to them over efferent fibres. For psychological purposes a simple sketch of the character and location of these structures will suffice.

The most vital part of the human eye consists of millions of tiny receptors which compose one of the layers of the retina (Fig. 8). These are the organs which, under the action of light, release the neural energies whose arrival in the brain is the immediate cause of vision. Clear and precise visual impressions

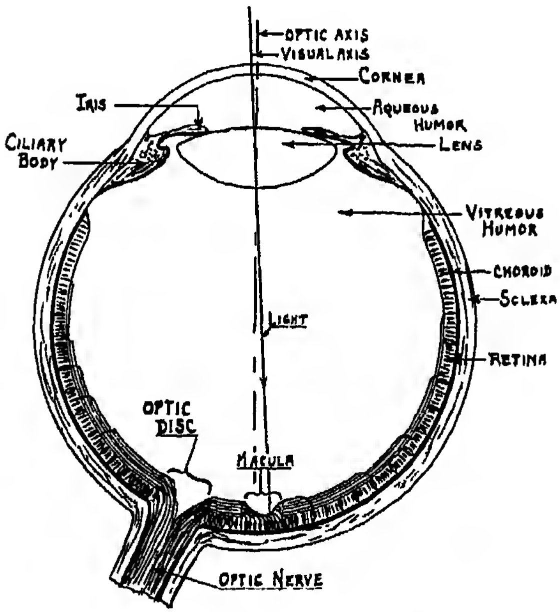


*Fig. 8.* Diagrammatic cross-section of the right eye with receptors greatly exaggerated in size and reduced in number, and with accessory cell layers omitted.

require, however, not *mere* stimulation of the retinal receptors, but stimulation of them in a certain definite and particular *way*, and the function of most of the remaining parts of the eye is to

provide for stimulation of this character. The receptors, for one thing, are not uniformly distributed over their hemispheric bed of tissue; they are vastly more numerous at a spot just temporal to the place where the sensory fibres leave on their way to the brain; this spot is called the *macula*. Objects seen directly are casting their rays upon the macula; macular stimulation is the first requirement of a clear image. Accordingly the muscles attached to the outside of the eyeballs must rotate them so that the entering rays will fall upon the macular area of each eye. Objects seen from the "eye corners" are not seen clearly because their light stimulates parts of the retina which are incapable of providing sharp and clear visual images.

The second requirement of stimulation if the image is to be satisfactory is that it be properly focussed. The light rays emitted or reflected from each point on the object and which spread steadily farther apart as they travel away from the point of radiation, must be bent or refracted back to a point again when they strike the retina. Such a point focus of light, or at least a close approach to it, is, along with macular stimulation, the physical condition for clear and sharp conscious impressions of objects. The function of the cornea and the lens is to shape the rays to a point upon the receptors. The muscles attached to the outside of the eyeball provide for macular placement of the image by rotating the eye into line with the light source, so that the rays, after passing through the pupil, will strike the macula, which is directly behind it. There are six of these muscles for each eye, fixed to the sides, top and bottom of the ball in such a way that movements in all directions are possible. Other parts of the eye likewise make contributions for the proper sort of stimulation. The function of the iris, for example, is to vary the size of its aperture, the pupil, in order to admit the right amount of light for comfortable vision; too much light as well as too little being unfavorable to a good image.

## THE SENSORY PATHWAY

At the receptor layer of the retina what amounts, in effect, to a transformation of energies takes place. The "physical image," composed of radiant energy, sets up a multitude of points of receptor activity patterned, as a whole, after the form and detail of the light source. This retinal image will be a curved and inverted translation of the pattern of the light

image, with its variations in wave-length and intensity, into a neural impulse "image" in which these features of stimulation are physiologically propagated to the brain. The central portion of this neural image will be a far more accurate representation of the qualities and details of the physical object than will the peripheral parts, owing to the greater numbers and specialized sensitivities of the macular receptors.

This neural image which arises in the retina may be thought of, as Troland[30] points out, as bearing, in a sense, a fair resemblance to the physical object. As the impulses begin their course toward the brain, however, this semblance is greatly diminished. Marked "condensations" will take place in the marginal portions of the physiological image, since many receptors in the retinal periphery combine their flow into a single fibre path along the optic nerve, whereas the central receptors have each their individual paths. The physiological image as a whole likewise shrinks enormously as the impulses travel concentrically toward the exit from the eye, its area being reduced, according to Troland, from over a thousand square millimeters to only eight. Moreover since impulses starting near the macula are closest to the point of exit they will reach it in advance of those arising in the farther regions, and the impulse pattern which travels over the optic nerve will be stretched out, so to speak, into a narrow cone-like form, impulses of central retinal origin being far in advance, during travel, of those from outlying areas.

As the impulses reach the optic chiasm (Figure 9) those derived from the right-hand sides of the retinas converge and pass backward together in the right optic tract; those of the left sides do likewise in the tract of the left side. The neural images from each eye are therefore split at the chiasm along a vertical line dividing them into two lateral halves, and in each tract two duplicate representations of retinal stimulations from the same sides are merged together. Certain qualifications of this statement with regard to macular representation will be made later. At the present point each tract may be regarded as transmitting two composite half-images. The fibres now pass backward toward the hindmost portion of the brain, suffering only one interruption at a synaptic juncture called the lateral geniculate

body. In their course across this juncture, however, the impulses preserve the essential pattern given them by stimulation at the retina. The fibres, moreover, deriving from the upper and lower halves of the retinas assume corresponding positions

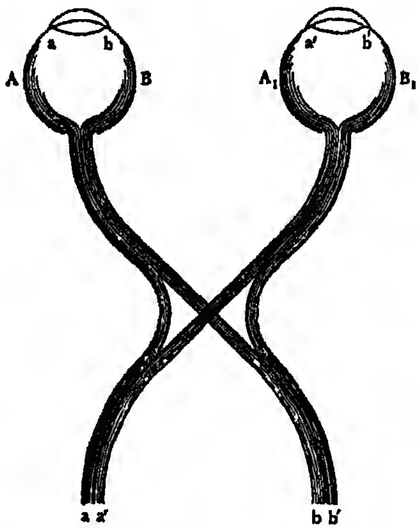


*Fig. 9.* The optic chiasm. (From Bills, General Experimental Psychology, Longmans, Green & Co.)

in the upper and lower halves of the tracts. This is true of specific retinal points as well as of areas; the fibres arising from a point located at a given distance and direction from the macula of one retina travels a course adjacent to the fibre from a point similarly located on the opposite retina.

The final destination of the impulses is represented in Figure 10. That portion of the superficial gray tissue (cortex) of the brain whose activity is the primary seat of visual consciousness —of "vision" in its most concrete sense—is the *area striata* or striped area, so called because of its characteristic streaked appearance. Most of this area lies on those inner surfaces of the occipital lobes of the hemispheres which face one another and thus are not exposed to view when an intact specimen of the brain is examined. The two hemispheres would have to be spread apart at their rearmost portion; the area striata occupies

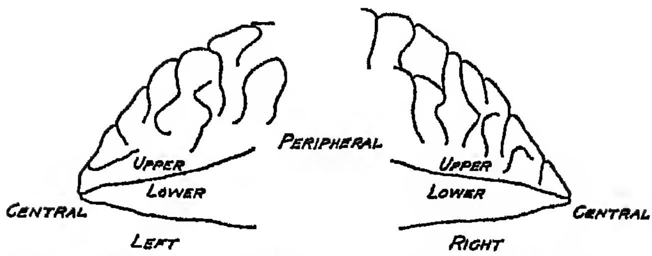


*Fig. 10.* Diagrammatic representation of the visual sensory cortex on the mesial surfaces of the hemispheres. The portions of the retinas projecting fibers upon the different parts of this region are indicated. (From Woodworth's Psychology, Henry Holt and Co.)

the inner lateral aspects of the occipital lobes. Figure 10 represents diagrammatically this spread-out appearance of the lobes and indicates the projection of the retinal regions upon this cortical end-station.

The right side of the figure represents the terminus of the fibres from the two right halves of the retinas. Fibre paths having their origin in the upper halves of the retinas are projected on the upper part of the visual area; those from the lower halves pass to the lower part of the area. Centrally derived retinal fibres are distributed to the hindmost part of the area; those of peripheral origin to the forward part. The area extends anteriorly (toward the front of the brain) about two inches from the occipital pole—the posterior end of the hemispheres. It is conveniently divided into upper and lower halves by the *calcarine fissure,* which is roughly horizontal in extension. The visual cortex extends also *into* this fissure, which is a deep fold in the surface layer of the brain. In general the points ranging from the macula to the periphery of the retina are connected by fibres with points distributed progressively from the posterior to the anterior portions of the striated area, with the dividing fissure corresponding to the horizontal axis of the retina.[21, 22] Within the area striata, including both hemispheres, all retinal points are therefore represented, but the cortical representation of the whole visual image is not a continuous unit here, each half being seated in a different hemisphere of the brain.

It follows from the above facts that if the fibres of one side—the right, for example, are severed behind the chiasm, im-

pulses from the two right halves of the retinas will be blocked, and vision for objects in the left halves of the two visual fields will be lost. (Owing to the crossing of the rays of light after entering the eye, the light from objects to the left of the fixation point falls upon the opposite or right side of the retina; objects above the point of regard cast their images on the lower halves of the retinas, and so on.) This is half-blindness or *hemianopsia.* The same sort of blindness would result from destruction of the area striata of the right hemisphere. Small, localized injuries to this area produce blind spots in the visual field which are similar in form for both eyes, their location and size being determined by the seat and extent of the injury.[23] The cortex of the occipital lobes adjacent to the striated areas is also concerned with vision on its sensory side in a way which will be mentioned later.

## THE MAJOR FIXATION REFLEXES

The occipital cortex adjacent to the area striata (Fig. 5) contains *the motor centers whose efferent discharges lead to automatic* rotation of the eyes in the direction of objects indirectly seen, and to the automatic following of moving objects, once they are fixated. The centers located here are not in direct control of the ocular muscles, however; efferent impulses originating at this point are sent first to a group of centers located in the midbrain, outside of and below the cerebral hemispheres, as indicated in the figure. These latter centers will hereafter be referred to as the "lower visual reflex centers," and the motor centers in the occipital lobe as the "higher visual reflex centers." The latter centers relay their orders to the lower ones, which distribute them to the specific muscle groups concerned in ocular rotations.

**Versions.** An object located to the left of the fixation point casts an image which falls upon the visual sensory surfaces outside the macula on the right halves of each retina (Figure 11). Following the outline of pathways previously traced, the impulses set up by these two areas of stimulation will become confluent at the optic chiasm and travel together over the right optic tract to the calcarine cortex (striated area) of the right side. Here a conscious visual impression results, namely: awareness of an object indirectly seen, i.e., seen to the left of the

momentary point of regard. If, now, the attention is not too strongly centered upon the present fixation point, or if the marginal impression possesses some unusual visual feature or quality, impulses will be automatically discharged to the lower

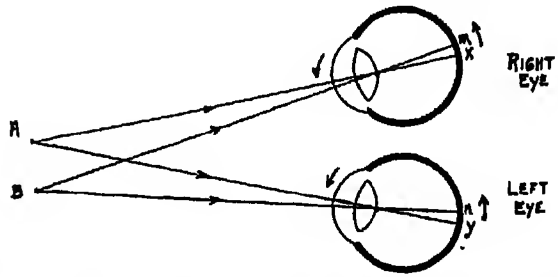


*Fig. 11.* Horizontal Version. The fixated object at point "A" casts its images upon the two maculas "x" and "y." The object "B" to the left of "A" casts its images upon the points "m" and "n." The rotation needed to place these images on the maculas must shift the latter toward the right, as indicated. The pupils, i.e., "the eyes," move to the left.

reflex centers which immediately relay them to the eye muscles. In this instance the lower centers which control the muscles attached to the left side of each eyeball will receive the discharge; their contraction must obviously turn the eyes to the left, a movement which places the maculas in the direct line of the rays reflected from the object. It will be noticed that rotations (versions) to the left are controlled by cortical reflex centers of the right occipital lobe, which is also the seat of visual impressions whose source is to the left of the line of regard. This is in keeping with the motor movements of the entire body, each side of the brain controlling the muscles of the opposite side. The converse relationships obtain for objects located in the right half of the visual field. Since the lower centers are also bilaterally arranged—a center to the left of the mid-line controlling the eye muscles of the left side, fibres from the right occipital cortex must accordingly cross over to the opposite side before making juncture with the proper lower centers. Horizontal movements of both eyes are controlled from a single side of the brain.

As, during version, retinal stimulation moves toward the macula, the resultant image becomes ascendant in consciousness; it reaches maximal definition (with focus) when the macula is

reached, and at this point the incitement to any further rotation ceases. The initial rotation, however, often carries the eyes too far—beyond the point of attention, and as this occurs the declining quality of the image furnishes the excitation to a corrective rotation in the opposite direction.[24] Several such corrections may be necessary before steady macular fixation is achieved. Fixation is therefore a series of progressive reflexes; several "aimings" are necessary before the target is hit. The function of the peripheral regions of the retina has often been described as comparable to that of a sentinel. They signal the occipital centers—and consciousness—that a new stimulus has arrived; a "stranger" has entered the visual field, and motor impulses are discharged which carry the macula toward the invader for investigation. The peripheral areas are especially sensitive to moving stimuli, which is appropriate to their sentinel function, since objects in motion may require immediate adaptive action. It is well for a wild animal, for example, which must be on constant guard against beasts of prey, to have sharp visual appreciation of movements in its environment. Accordingly motion can be sensed considerably in advance of recognition.

Visual perception does not take place during movements of fixation; these entail intervals of interrupted vision.[25] Such movements are well seen, Duke-Elder suggests,[26] when a series of moving objects traverses the field of vision, as in observing the items of a landscape through a train window. The eyes follow one item until the reflex is stimulated by another succeeding it in the line of travel, and then jerk quickly to a new fixation. During "pursuit" when a moving object is steadily followed, ocular movements are continuous and a clear visual impression is maintained.[27] Such pursuit movements, according to Dodge, tend to persist after the occasion for them has ceased. After following moving objects with the eyes for a period, if one then attempts to fixate a stationary object, the pursuit movements may continue automatically for a brief interval, arousing the illusion of movement (of objects) in the opposite direction.

Holmes[28] believes that there are two distinct and opposed reflexes involved in fixation. One is stimulated by an extramacular image and consists of a rotation which displaces the image toward the macula. The other is of macular origin and

*maintains* the image in its central position by turning the eyes if the object is in motion, or by keeping them in a fixed posture when the object is stationary. The evidence for this view will be discussed at a later point. The reflexes, assumedly, are "opposed" only in the sense that every new fixation entails a breaking of the one which preceded it. Here the psychic character of these reflexes is clearly seen, since the degree of attention or interest aroused by the marginal impression will determine whether a version will be stimulated, or whether the direction of fixation is to remain unchanged -whether, i.e., the "macular reflex" is to override competition.

The versions include all ocular movements in which the visual axes remain parallel; upward, downward, and oblique rotations will therefore fall within this group, along with horizontal movements. Light from objects in the upper part of the visual field falls upon the lower part of the retina, which is connected by fibers with the lower part of the area striata. An upward movement of the pupils (downward displacement of the maculas) is necessary to bring such images upon the most sensitive part of the retinas. For the detailed muscle functions the student is referred to texts in physiological optics.

Convergence. The images of an object located nearer to the observer than the point of momentary fixation fall upon the retinas temporally to the macula (Figure 12). Obviously, to

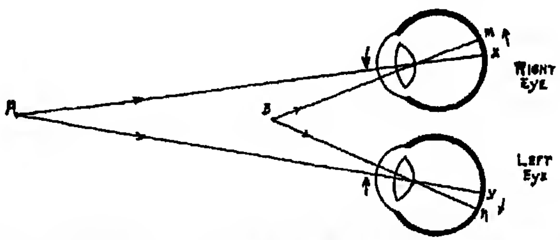


*Fig. 12.* Convergence. The fixated object "A" casts its images on the two maculas "x" and "y." The nearer object "B" casts its images at "m" and "n." To bring these images to the maculas the eyeballs must rotate in the directions indicated.

bring such images to the maculas the eyes must rotate inward. The versions, during which the axes remain parallel, are called conjugate movements. Movements in which the axes are not parallel, as in convergence and divergence, are called disjunc-

tive. Convergence, like the versions, is a psycho-reflex, in that the effects of stimulation must register a change in consciousness. The impulses must pass, therefore, to the higher reflex centers in the occipital cortex before their discharge to the lower centers in the mid-brain which directly control the individual muscle movements. The purpose of convergence, like that of the versions, is to bring the two images to the maculas; owing to the difference in the initial position of the images leading to convergence the character of the rotations required differs correspondingly. Convergence movements will be recognized, however, as merely a variation on the version formula. The muscles which effect convergence are essentially the same as those active in lateral versions, but the neural mechanism governing the two types of movement are distinct. Since images fall to the right of the macula of the right eye and to the left of that of the left eye their registration in the visual cortex will be bilateral, in contrast to that for the lateral versions. Entry of the images in consciousness, however, is not in itself sufficient to evoke the reflex. As in the case of the version stimulus, a degree of competitive interest must be aroused which exceeds that centered upon the present point of convergent fixation, or, for that matter, of any other source of stimulation. The images must register, in other words, not only in consciousness but in *attentive* consciousness, in which a definite desire to see is present.[29]

The straightening out of the visual axes from a convergent position toward parallelism is known as divergence, or negative convergence. Duane[30] regards it as an active reflex, due in part to contraction of the muscles attached to the temporal sides of the eyeballs. He advances as evidence the fact that marked strain is experienced by individuals whose divergence is being tested with prisms; other cases of antagonistic muscle movements in the body, he maintains, represent active contraction. Others, among them Duke-Elder, believe that divergence is best regarded as a relaxation of convergent effort, in which the eyes simply return to the balance of tonus represented by the primary position of rest, with the axes parallel and directed straight forward.

There is evidence that version and convergence represent two distinct reflex organizations. Convergence may fail while all

conjugate lateral movements are preserved.[81] Correspondingly there may be paralysis of side to side movements with retention of convergent capacity.[82, 83] An eye, for example, may be unable to turn inward upon stimulation for a lateral version, yet turn inward readily when converging with its fellow upon a near point. The impulses released by stimulation on the temporal sides of each retina are transmitted to the occipital centers of both sides, following the sensory paths described earlier; the efferent discharge to the mid-brain center for convergence therefore issues from the occipital motor centers of both hemispheres.

**Accommodation.** The delicate muscle movements which regulate the curvature of the crystalline lens for the achievement of a proper focus of the retinal image are also to be classed, along with versions and convergence, as expressions of psycho-reflexes. The physical condition for well-defined conscious impressions of objects is a single point of light stimulation on the retina for each point of light emission on the object. Each point on the object may be thought of as sending out a solid, diverging cone of rays toward the eye. The function of the lens and the other refracting surfaces of the eye is to bend these rays so that the cone of light, as it issues from them, will converge back to a point upon the retina. If the refractive power of the lens is insufficient, the ray-cone will not converge or taper steeply enough to come to a point on the retina, and the consequence will be a circular surface of stimulation. Such a surface is called a *blur circle.*

The larger such circles the poorer the image. The function of the lens is to reduce, so far as possible, the size of the blur circles in the direction of a point of stimulation. Anyone who has tried to set fire to a piece of paper by bringing the sun's rays to a sharp focus upon it with a "magnifying glass" will recall that this is done by so regulating the distance of the lens as to bring the luminous area on the paper down to a minute spot. The lens of the eye performs a similar operation on the retina by increasing its own curvature, since its ray-bending power varies inversely as the radius of its curvature. The form of the lens is regulated by the action of the small (ciliary) muscles attached, by way of the suspensory ligament, to its rim. Before this reflex adjustment can occur, however, the unfocussed

light stimulation on the retina must register a blurred image in consciousness. There must be present in the mind, moreover, an *attentive* fixation, or desire to see clearly ("psychic demand"). This psychic fixation is the pre-condition of visual fixation and visual focussing.

Obviously, for every momentary ocular adjustment which mediates a defined conscious impression of an object there will be many other objects—those nearer and farther, for example, which are "out of focus." These blurry images constitute the general background of visual consciousness, the undefined context within which sharply defined visual impressions are apprehended. There is a vast number of blur circles on the retina at all times, whose source is the general field of objects which are indirectly seen. The blur circle alone, therefore, is not a stimulus for the psycho-reflex of accommodation. In the same sense extra-macular images on corresponding sides of the retinas, or those falling temporal to the maculas, are not the adequate stimuli for versions and convergence, respectively. The factor of mental demand for visual knowledge of the source of such stimulation,—for a more intimate scrutiny of this source, is the internal condition which must be present if the stimulus is to arouse a response. In its absence the stimulus, while it affects consciousness, elicits no ocular changes. The student should now appreciate the significance of the classification of these reflexes as "psychic," and of the statement that not mere awareness but "psychic demand" is the mental requirement for ocular fixation and focus.

The "physiological image" resulting from stimulation must therefore pass through the occipital cortices (the *conscious* centers, as distinguished, for example, from those involved in the photo-pupillary reflex), whereupon impulses are discharged, as in the case of the earlier-discussed psycho-reflexes, to the centers of the mid-brain. Here the immediate motor center for ciliary control lies closely adjacent to the centers governing constriction of the pupil and the contraction of the eye-converging muscles. These three centers are simultaneously active whenever fixation for close vision occurs—the "near reflex." It may be added that visual focus is always a relative affair, i.e., an image sufficiently defined for all ordinary purposes is achieved by a reduction of the size of blur circles which approaches but probably never ac-

tually reaches point-stimulation. Differences of image clarity are therefore quantitative; "the difference between distinct and indistinct vision is one of degree and not of kind."[84]

**Conditioning in the Accommodation-Convergence Relationship.** As a fixated object draws near the eyes must rotate inward to keep the image on the maculas; they must also accommodate, since the nearer the object the more divergent are the rays which enter the eyes, and the more they must be refracted, therefore, in order to converge backward to something approaching a point on the retina. For objects within a distance of about 20 feet stimulation for the two reflexes is supplied simultaneously and the responses are therefore concurrent. When two independent reactions occur together repeatedly the conditions are met, as the student will recall, for the establishment of a linkage or association between them.[85, 86, 87] If such a bond exists, it should be possible to evoke either of these reflexes by supplying the stimulus for the other. The stimulus for accommodation should produce some degree of convergence—"accommodative convergence," and the stimulus for convergence should result in some accommodation—"convergent accommodation." This can be tested by having a person converge for a near point, and relaxing accommodation by interposing a convex lens which will take over the work of the ocular lens for the fixation distance, thus releasing the accommodation reflex from its usual task. Under these conditions there should be a partial relaxation of accommodation, with a residue, however, resulting from the convergence stimulation.

One investigator[88] found, for example, that with a normal eye about 3 diopters of accommodation are needed to see small print clearly at a distance of one-third meter. When a convex lens was introduced accommodation relaxed, but rarely did so completely; for this reason 3 diopters of plus power of the artificial lens could not be successfully substituted; the subject refused to "accept" this much. Why did accommodation not fully relax in the absence of its normal stimulation? It seems clear that in this case the acting stimulus for convergence was also supplying adequate stimulation for the associated (conditioned) reflex of accommodation. For when the stimulation for convergence was abolished by means of a prism, accommodation gave way at once and the 3 diopters of plus were accepted.

Conditioned convergence may be similarly disclosed by releasing this reflex (with a prism) while the stimulus for accommodation remains active. The amount of convergence reflex persisting after the withdrawal of its natural stimulus will then be a measure of the degree of conditioning established. Tait studied 500 cases between the ages of 10 and 14. The maximum convergent accommodation found was 2 diopters; of accommodative convergence, 21 prism diopters. Eleven subjects had neither of the associated reflexes. Most of the cases were regularly distributed between these two extremes. On the average there were 8-14 prism diopters of associated convergence (accommodative convergence) and 1.50 diopters of associated accommodation. High correlation was present between the two associated reflexes; in very few cases was one present without the other.*

**Voluntary Control of Ocular Movements.** Two groups of nerve centers concerned with ocular motions have been described; the higher reflex centers in the occipital cortex, and the lower centers for immediate innervation of eye movements, located in the mid-brain. The latter centers may be regarded as the distributors of specific excitations to individual muscle groups; the former as issuing the more general commands for whole movements whose details are handled by the mid-brain centers, which are in more intimate connection with the muscles concerned. Complex, delicate and precise though these functions are, they represent an automatic mechanism, none the less —a highly sensitive reflex machine whose operations are determined by the form and location of retinal stimuli, on the one hand, and by the direction and degree of attention on the other.

A considerable distance from the occipital centers, near the opposite end of the brain, in fact (Figure 5), are those which are the seat of intentional or willed movements of the eyes.

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*Other aspects of ocular conditioning are suggested by Eames. In the condition of hypermetropia, for example, in which degrees of accommodation beyond the normal are necessary for clear focus, this excessive reflex becomes associated with convergence, and corrective lenses may be unable to reduce it, i.e., to inhibit the effects of conditioned stimulation. Eye-strain, again, resulting from occupational conditions which are also the stimulus to fatigue symptoms, emotional and glandular disturbances, etc., may finally become so strongly associated with these reactions as to arouse them in the absence of their original causes. Ocular fatigue and pain experienced at certain times of day are suggested as possible conditioned reactions to incidental stimuli which have frequently accompanied the work done at such times—the work being the original cause of the visual symptoms.

They are in the second frontal convolution of each hemisphere. Stimulation of these areas produces conjugate turnings of the eyeballs. The character of the movement so produced depends upon the site of stimulation. Thus unilateral stimulation leads to versions to the opposite side, which may be horizontal or oblique; bilateral stimulation evokes upward and downward movements, and convergence of the eyes, according to stimulation. These stimulus-response relationships closely resemble those pertaining to the occipital centers.[39] The voluntary centers, like the occipital reflex nuclei, effect their movements only through the mid-brain relay; the latter centers are thus "under orders" from both of these higher agencies. The centers of the frontal cortex, however, have the greater authority; if both frontal and occipital centers are simultaneously stimulated for opposed movements the effect of the frontals predominates.[40, 41] Of the three major types of visual movement discussed in this chapter only two are normally under voluntary control: version and convergence, namely. Occasionally a case of ability to change accommodation at will is reported.[42, 43] One of Zentmayer's patients was able, "with no effort," to blur his vision for a period and restore the image to clearness again whenever he wished. Such reports are rather rare, however.

There is plenty of evidence for regarding voluntary and reflex ocular movements as two functionally independent systems. A case reported by Riley[44] was unable to move his eyes toward one side, but once the gaze was fixed on an object the eyes remained centered upon it during a turn of the head, the movement thus performed being impossible by voluntary effort. Holmes[45] has described similar disorders.* When the eyes had reflexly followed an object to a new position they remained in

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*One of Holmes's patients, owing to cerebral injury ". . . was unable to look to the left, upwards or downwards, or to converge on a near object, and deviation to the right was seriously restricted. When, however, his eyes were fixed on a point he could follow this point when it was moved slowly in any direction, and if his head was rotated passively his eyes remained in their original direction, in other words they deviated through a corresponding angle in the opposite direction. Frequently too his eyes turned in the direction of an unexpected sound." In other cases there was failure of this fixation reflex, resulting likewise from brain injury. When the patient is asked to look at an object ". . . he moves his eyes promptly and accurately to it, but he cannot keep them directed on it; almost at once they recede towards their position of rest and are brought back by a series of efforts which are obviously purposive and voluntary. The same disturbance is seen when the eyes attempt to follow a moving object, especially if the movement is not uniform in rate, and when the head is moved passively during an attempt on the part of the patient to maintain ocular fixation." (Ref. 10, Pp. 568-570)

this fixation in spite of the patient's efforts to move them away. If a screen, however, was placed before the eyes, thus cutting off stimulation for the reflex, the eyes rotated back to their first position. If the eyes were fixed on a point while the head was rotated they maintained fixation so long as the point was in view. The eyes followed a moving object if the movement was slow, but a quick movement, which displaced the image from the macula, destroyed the reflex and the eyes ceased to follow. The paralysis of voluntary control in such cases results in a certain exaggeration of the fixation reflex—a "release phenomenon," according to Holmes. The reflex fixation mechanism, liberated from the influences of the frontal centers, exhibits an unusual and machine-like tenacity in following the source of stimulation, so long as the latter remains on the macula.

Despite the capacity for voluntary control the ocular movements occur on a predominantly reflex basis. Here as elsewhere such control is merely a general supervision and orientation of essentially reflex mechanisms. If conscious effort were required to govern the continuous slight compensatory movements of ordinary visual fixation, an extremely distracting and bothersome burden would be imposed upon attention. In the maintenance of a fixation during walking, during movements of the head, however slight, and even in breathing, the position of the eyes relative to the object is constantly changing, entailing a corresponding series of corrective movements, large and small. This is not to deny, of course, that many ocular movements of fixating and exploration may be wholly voluntary in origin. Simply, the finer details of adjustment in fixation, and especially its maintenance, represent the more minute work, seldom noticed, of delicate subordinate reflexes. The consequence of the absence of such reflexes is in evidence among Holmes's observations of cases of cerebral injury, in which the patient is capable of voluntary fixations, the eyes, however, repeatedly slipping away to the primary position and having to be forced back to the object. In general, as Holmes suggests, these automatic postural functions in vision are in class with the unconscious and involuntary maintenance of various bodily postures in standing and sitting, and in the preservation of equilibrium.

The evidence indicates, as mentioned before, that the primary mechanisms governing these reflex adjustments are located in the neighborhood of the same calcarine cortical area (area striata) whose activity mediates conscious visual impressions, the afferent fibers being those previously traced back from the retinas. The efferent paths pass directly to the regions of the mid-brain nuclei (lower reflex centers) where the final execution of movements is prepared.

In summary, it appears that voluntary ocular control is superposed on a reflex foundation, and that this foundation is primarily a function of the occipital lobes, subordinately a function of the mid-brain. In the occipital cortex are seated the initiative centers for convergence of the axes, accommodative adjustment of the lens, and for two kinds of fixation movements, one aroused by extra-macular stimulation and engaging in rotation of the macula toward the image, and the other a "maintenance reflex" keeping the image upon the macula during movements of the object or of the observer. But retinal stimulation, it may again be emphasized, is only a partial determinant of these responses. Inseparably bound up with their operations is the psychic factor of attention which selects now this and now that impression as the new focus of the multiple adjustive reflexes, exerting a continual "make and break" action upon the fixative functions. Equally important, moreover, is the subtle cooperation between these reflex organizations and the voluntary centers, in which the reflex machinery supplements and supports the grosser willed movements and relieves conscious effort of the more pedestrian features of the work of seeing effectively and comfortably. Marvelously smooth coordination between frontal and occipital centers is necessary in so-called voluntary movements of the eyes. Fundamental to the initiative of both centers are the mid-brain operations, ensuring harmonious team-work of the two eyes in all actions, reflex or voluntary.

## OTHER FIXATION REFLEXES

A few words may be devoted to a description of some fixation movements which are non-retinal in origin. If a person is turned about in a revolving chair his eyes will rotate in the opposite direction with sliding motions followed by quick jerks

of recovery. The reflex as a whole is known as *nystagmus.* The eye movements occur when the lids are closed, and may be observed with the finger tips. These movements occur whenever the head is rotated and are involuntary. To inhibit them some object moving at the same rate (angular) as the turn of the head must be fixated, as, e.g., the end of the nose.[46] Since the movements occur with eyes closed or with the subject in an enclosed revolving box in which his visual field rotates with him, they are obviously not responses to external stimulation. Their purpose is to assist fixation, to compensate for head movements in one direction by eye movements in the opposite direction, thus keeping a fixated object in direct gaze. They perform this function accurately, according to Dodge, only for head movements of moderate rate and not too large an amplitude. So long as the compensatory eye movements are accurate the fixated object appears stationary; if they are made too quickly for proper fixation the object exhibits an illusory movement.

Reflex eye movements of similar function occur during motions of the head in any plane. When the head is bent forward or backward the eyes rotate upward or downward, respectively; when the head is laterally tilted, to the right, for example, the eyes roll about their axes to the left, to compensate for the deflection of the head and thus maintain the eyes and the object of regard in a constant relationship, since the compensatory movements are always opposite in direction to those of the head. When voluntary control of the eyes is lost, the reflexes in nystagmus are retained; when the reflexes themselves are abolished, accurate fixation of objects while the head is in motion becomes impossible even though the normal voluntary control of head and eyes is preserved.[47]

There are ocular reflexes, therefore, whose stimulation consists of head and body movements and general changes of posture. The receptor for this stimulation is located in the internal ear, where a mechanism is seated having to do, not with hearing but with the registration of changes in bodily position and equilibrium. It is connected with the eye muscles by way of the mid-brain centers discussed earlier. Section of the afferent nerves connected with these receptors abolishes

the reflexes and leads to a loss of fixation ability during head movements.[48]

The receptors referred to are the *semicircular canals,* the *utricle,* and the *saccule.* These organs are closely adjacent to the essential receptor for auditory stimuli (the cochlea) but have their own sensory nerves and are not concerned with the auditory function. Early in evolutionary development the function of the ear was to respond, not to air waves but to changes of position. The semicircular canals consist of tubes arranged in the major planes of the head movements, and contain liquid which is set in motion by such movements. Each tube has cells on its inside from which hair-like processes pro-

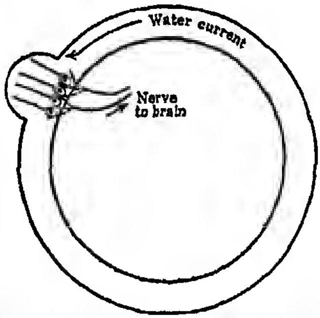


*Fig. 13.* The diagram shows how the sensory cells in the semicircular canals are stimulated. When the head is turned in the direction opposite to that shown by the arrow there is a reverse flow of the liquid, due to inertia, which exerts pressure against the hairlike processes projecting into it. (From Woodworth's Psychology, Henry Holt and Co.)

trude into the liquid. Motions of the head produce, by inertia, a back flow of the liquid in the tubes; this flow exerts a pressure against the hairs which acts as their stimulus (Figure 13). The other organs mentioned also contain such hairs, in which small calcareous pebbles are imbedded. Inclinations of the head cause these pebbles, again by inertia, to press against the hairs. The latter are attached to sensory fibers which send impulses to the brain. Sensations of loss of balance and dizziness are the conscious reactions resulting from impulses set up in this group of receptors.

It is the reflex ocular results of such stimulation which are of concern here. The compensatory rotations of the eyes resulting from upward, downward and lateral rotations of the

head express the control of the utricles and saccules over the eye muscles.[49] The nystagmic movements are the reactions to stimulation of the receptors in the semicircular canals. These are "true" or physical reflexes, subserved by centers below the cerebral cortices.[50, 51] In cases of destruction of the receptors concerned with them objects appear to oscillate when the head is moved; the disorder is transient, however, and the reflexes are not, according to Holmes, essential to fixation.[52] They are normally supplemented by reflexes of retinal origin. Movements of the trunk when the head is fixed in position also lead to compensatory ocular movements, indicating reflexes originating in the contraction of the neck muscles. These occur likewise through the mid-brain nuclei.[53] Impulses from many different sources, it thus appears, converge upon these lower reflex centers.

## EYE MOVEMENTS AND PERCEPTION

Most people would probably say that their eyes, in reading, for example, move smoothly and continuously back and forth over the lines while the mind just as continuously takes in the meaning during these movements. It has been known for many years, however, that this is not the case. The movements turn out on analysis to be a series of quick jumps or jerks (saccadic movements), and pauses which are much greater in duration. It is only during the pauses that perception, i.e., actual *seeing*, takes place. And only the sweep of the eyes from the end of one line to the beginning of the next is a continuous movement. A clear visual impression is possible only when the eyes are at rest upon the object, whether it is stationary or in motion. In the latter case the moving fixation is called a "pursuit movement." These are moments of clear and relatively continuous vision, interrupted only by slight corrective jerks when the eyes for an instant lag behind the object.[54] The jerk-and-pause type of movement, however, seems to be the characteristic kind. Dodge found that an attempt to move the eyes slowly and continuously from one point to another always resulted in one or more unconscious pauses. If the line of movement passed through a bright light the observer, on closing his eyes, reported a series of after-images of the light, proving that the eyes stopped at points along their course. The shortest of these rests were about 0.2 second.

By a simple experiment Dodge[65] demonstrated that true seeing does not occur while the eyes are in motion. A paper cone was placed between an object and the eye in such a manner that the object was visible only when the pupil was directly in front of the small aperture in the apex of the cone. The base of the cone was large enough to cover the object completely. If the eye was then moved without interruption through a large angle from one fixation point to another, its course passing across the aperture of the cone, "absolutely nothing" was seen of the object. When the experiment was repeated without the cone the object was seen no more clearly during the eye movement between the fixation points than when seen by indirect vision from either of these points. This although the line of vision during movement passed directly through the object.

**The Eyes in Reading.** Studies of eye movements in reading have disclosed many interesting facts. Such movements, as stated before, consist of a series of jumps and pauses, the jumps occupying but a small fraction of a second. Most of the time spent in reading is fixation time, the saccadic movements requiring only about one-tenth of the total, and probably depending chiefly upon the speed of the reflex. No actual *reading* takes place during the inter-fixation periods, though of course the processes of mental assimilation may be more continuous. The rate of comprehension of meaning appears to be highly important in determining the speed of reading; the perceptual grasp,

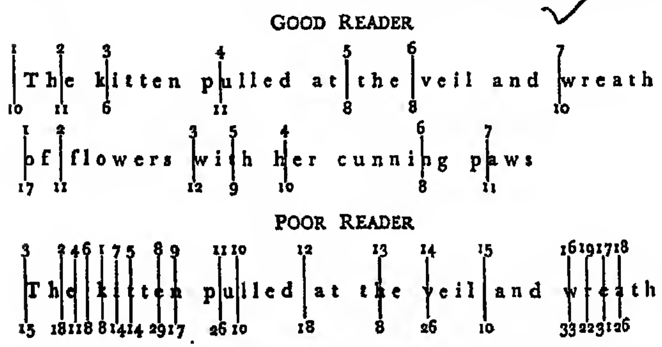


*Fig. 14.* Eye pauses in reading. The vertical lines represent eye pauses; the numbers at the top of the lines represent the successive order of the pauses; the numbers at the bottom of the lines represent the length of the pauses in fiftieths of a second. (From Bills, General Experimental Psychology, Longmans, Green & Co.)

or number of words taken in during each fixation, being also important.[56] The time required for such perceptual acts varies considerably from one person to another. During the early years of learning to read the number of fixations per line decreases rapidly, likewise their duration. Rapid readers show relatively few fixations, but this also depends greatly on the familiarity of the text. An important difference between good readers and poor ones is the number of "regressions" made in each line (Figure 14). Backward movements with re-fixations are especially noticeable in children and untrained readers, indicating incomplete comprehension.

Elaborate methods have been developed for the scientific study of eye movements in reading.[57, 58] The outstanding technique consists of projecting a beam of light upon the cornea of the reader. When the eye moves the beam is correspondingly deflected and its movements are recorded, by means of the beam reflected from the cornea, upon a moving photographic film. The projected beam is rapidly interrupted (50 times per second) by the vibrations of an electric tuning-fork or by a perforated disk revolving at the above rate. The record then consists of a series of dots, each dot standing for one fiftieth of a second of time. The duration of fixations and jumps as well as their number may then be computed. Earlier methods, some of which made use of plaster casts or capsules directly attached to the cornea, and containing small mirrors imbedded for reflecting light to the camera, were found to have disadvantages and to be less satisfactory than the one described above.

## THE SENSORY ASPECT OF VISION

The emphasis in the preceding sections of this chapter centered upon the motor features of visual reactions, chiefly those adjustments involved in ocular fixation in which a psychic factor is an integral part. The sections following introduce some of the fundamentals in the sensory phase of vision, which will be continued and further developed in later chapters.

Outstanding among the stimulus-response relationships which comprise the visual system is the fact that although we have two eyes and therefore two ocular images we are normally aware of but one visual or mental image. Despite the stimu-

lation of two receptors there is usually but a single conscious response. Each eye operating alone can supply us with an adequate image of an object; both eyes operating together provide a single image hardly distinguishable from it, a case, apparently, where one plus one equals one.

But it is not always true that single vision results from double stimulation. "If you fix your eyes steadily upon some object in the field of vision,—a tree, let us say, seen through the open door,—the surrounding objects appear in their proper shapes and places; the space-values of the field are entirely normal. But if, now, you hold up a pencil, at arm's length, between the eyes and the point of fixation, you find that it doubles, that you see two pencils. And if, after this experience, you consider the field of vision somewhat more carefully, you will find that it shows a good deal of doubling: the tip of the cigar in your mouth splits into two, the edge of the open door wavers into two, the ropes of the swing, the telegraph pole, the stem of another, nearer tree, are all doubled. So long, that is, as the eyes are at rest, only certain objects in the field are seen single, the rest are seen double."[59] Double vision, it seems, is just as definite a fact as single vision, and both call for explanation.

In the above illustration the object directly fixated casts its images upon two retinal areas. Such areas, whose stimulation results in a single visual impression of the object, are known as *corresponding* areas, or, considering the more minute object-points of light radiation, the retinal points whose stimulation causes the object-points to be seen singly are said to be corresponding points. During the binocular fixation of a single object, seen as single, other single objects are seen as double, and the retinal areas stimulated in this case are called *non-corresponding areas,* each comprising non-corresponding points. The observable facts are that some objects are seen single, others as double, and it is inferred from this that the areas which mediate single vision bear a peculiar relationship to each other;[60] they are unique pairs, or mates, connected in such a manner that a unitary visual impression is the result of their simultaneous stimulation. Other areas, not related in this way, do not combine their impressions, but register them separately in consciousness, or at least may be observed to do so when a

deliberate attempt is made to distinguish them. Ordinarily no attention is given to double images—the fixated object being the center of attention—and most people are seldom aware of their existence.

With a given fixation of the eyes, objects located at a number of positions in space may be observed to be seen singly. Such objects must, of course, be located in that portion of the total visual field which is common to both eyes, i.e., the binocular field. Not only, then, is there unification for the two images of an object directly fixated but also for a number of objects which are indirectly seen. Objects located nearer and farther than the point fixated, on the other hand, are seen double, which may easily be observed with a couple of pencils or the fingers. It will be noticed that the closer such objects are approached to the plane of fixation the smaller the distance between the double images. Finally, as this plane is reached, the images unite. By certain methods it is possible to determine all the positions of objects in the field which, with a given fixation, are seen as single. It is then disclosed that for each area on one retina there is one and only one area on the other retina which "corresponds" to it, i.e., whose simultaneous stimulation will result in single vision. All other areas will be "non-corresponding," and their stimulation arouses double vision.

The next step is to determine where on the retinas these corresponding areas are located, the law according to which they are distributed. If imaginary lines be drawn from each point in space which is seen single, for a given fixation, through the optical center of each eye, the two lines projected from each such point will fall upon corresponding retinal areas. Since the retinal image is inverted with relation to the object, a point to the right of the fixation line will project to the left sides of the retinas; a point above this line will project upon the lower halves of the retinas. The lines drawn from the fixation point itself will necessarily fall upon the two macular areas, since it is the purpose of fixation to direct light rays to these portions of the retina. Figure 15 represents the results of such projection. It will be noted that the pairs of corresponding areas are located at the same distance and in the same direction from the

macula of each eye. The two visual images of any object whose retinal impressions (stimulation) fall upon such areas will be located in the same position in space,—will, in other words, coincide or be seen as one.

The statement so far merely defines the character of the double receptor stimulation which is necessary if a single mental

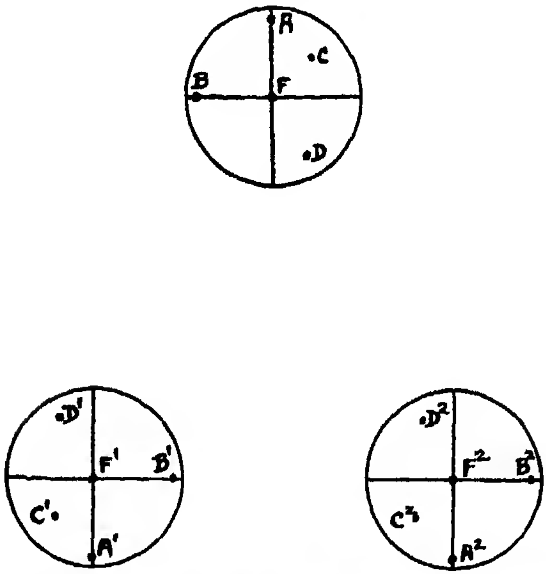


*Fig. 15.* The dots in the upper circle represent the location of points in space (fixation being at F) whose images are seen as single. The dots in the lower circles represent the projections of these points on the retinas, the latter points being, by definition, corresponding. (From Carr, Introduction to Space Perception, Longmans, Green & Co.)

response is to result. The problem as to *how* a unitary response is made to such stimulation still remains. It will be recalled from the description of the sensory pathways in vision that the optic fibers arising from the right halves of the two retinas pass backward to the area striata of the right cerebral hemisphere, owing to the division at the chiasm; those from the left halves passing to the left hemisphere. The two right halves are *corresponding* halves of the retinas; likewise the two left halves. It will thus be seen that each pair of the corresponding areas above described project their fibers upon the same side of the

cortical visual area, and it is in this area that vision as a conscious experience is seated. An injury to the right area striata, in destroying the terminal of fibers from the right halves of the retinas, produces blindness for objects in the left halves of the visual field. The evidence supplied by such injuries is one of the main sources of our knowledge of the course of the connections between the eyes and the brain.

Detailed anatomical tracings of the fiber paths have shown, moreover, that not only do corresponding retinal *halves* connect with the same halves of the visual area, but that the fibers from each pair of corresponding *points* or areas also terminate in the same local points or areas in the visual cortex. This fact has two important bearings in relation to visual theory. On the sensory side it offers an explanation for single vision, since if the fibers converge upon a single point in the conscious centers, single vision is what would be expected in consequence. The anatomical basis, at least, of a unitary response is provided. Evidence has been offered for the existence of a cell layer in the visual area to which fibers from pairs of corresponding points bring their impulses, and which therefore may function as a fusion center.[61] Others believe that our present knowledge is inadequate to the task of localizing the activities basic to fusion.[62] A further consequence of the anatomical relationships is that a structural basis is provided for a juncture between fibers from pairs of corresponding retinal areas and a common *efferent* pathway, thus making possible a unitary ocular adjustment to double stimulation. The convergence of afferent fibers upon the visual cortex is regarded by Duke-Elder, in fact, as having significance chiefly for the reflex motor functions, sensory fusion representing the product of a higher psychic synthesis. The emphasis on the efferent significance of the convergent paths seems warranted in view of the precisely co-ordinated character of conjugated movements of the two eyes. In such parallel movements the external rectus (temporal side muscle) of one eye operates, for example, with the internal rectus (nasal side muscle) of the other as a single function,

expressing, it would appear, the activity of a unitary central organ.*

The Replacement Theory. If the images of the two eyes are alike, the combined binocular image does not differ from either of its components. There must be some kind of cortical mechanism underlying this unification process by means of which "one plus one equals one." The possibility that impulses from corresponding retinal points may converge upon a single cortical point may be further developed. Verhoeff[98] suggests that each such pair of retinal areas is represented in the conscious centers of the brain by a single "conscious visual unit," the visual image as experienced being composed of these latter. The reaction of the single cortical units basic to visual consciousness is assumed to be governed by the all or none law; they will respond to maximum capacity or not at all. A cortical unit will therefore respond maximally by excitation from either one of the retinal units, or points, connected with it. The response will not be affected by impulses from one retinal unit when once aroused by those from the other. Unification of images thus takes place by exclusion or "replacement," rather than by an addition, or summation, of the "corresponding" and component parts of images.

The conscious image, according to this view, is a constellation or pattern whose elementary parts are contributed *either*

*It is still an issue, apparently, as to what extent the corresponding relation between retinal areas is innately established, and to what degree it is a result of experience. According to Carr[80] (Pp. 171–184) the facts indicate that the relations between the macular areas is inborn and the assumption is permissible that the same is true for all other pairs of corresponding areas, though the stability of the relation may be "materially influenced" by experience. In cases of convergent strabismus (cross-eyes) the image of an object fixated falls upon the macula of one eye and upon an extra-macula (non-corresponding) area of the other. The image of the fixated object should therefore be doubled; in most cases the doubling is not noticed, owing, theoretically, to a habit of inattention, or "suppression," though it *may* become perceptible by training. This fact, along with the few cases in which double vision persists, is accepted by Carr as indicating that the correspondence relation is not a result of experience, since the relation is not established in these cases between macular and extra-macular areas.

Duke-Elder, on the other hand, states the case for the development of a "false macula" and a new system of correspondences. After correction of the squint such individuals may use the false macula preferentially. Monocular diplopia may occur when the normal eye is covered. The normal relationship, accordingly, is not rigid, but capable of considerable alteration.

by one retina *or* by the other. When the two images are sufficiently similar, one is not conscious of the replacement process. If, on the other hand, two markedly unlike images are projected on the retinas, replacement may easily be observed. When, for example, a row of horizontal lines is seen by one eye and a row of vertical lines by the other, the resultant image consists of either the one pattern or the other, alternately (total replacement), or local fluctuations between the two patterns occur, horizonals in one area with verticals in another. In general it is attention which determines which elements will be dominant, and what proportions of the components of either stimulus pattern will achieve expression in consciousness.

If the object of regard be a uniform white surface, for example,[64] an equal number of units of the image will be supplied by each retina. If a dark glass screen is placed before one eye, with the retinas contributing an equal number of units of stimulation, the resultant conscious image would exhibit a brightness value midway between the two monocular impressions, the total effect of the individual point replacements being similar to that obtained by mixing on a color rotator. Since, however, the dark area will attract more attention, more of the units of the binocular image will be contributed by the corresponding retina, and in consequence the image will be darker than the mean brightness value of the monocular impressions. If on a white ground a black line is drawn and projected on the right retina, it will appear wholly black or nearly so at first, owing to the diversion of attention toward it. As attention is withdrawn, or fluctuates, the line will appear less uniform in blackness or may even disappear. The phenomena of rivalry and suppression are thus accounted for in the same terms as image unification.

Every retinal image, then, has its substitute, which can register in the brain in its place, to various degrees or as a whole. The proportions of the conscious image contributed by each retina will depend upon attention and the variables which in turn determine the direction and degree of attention—interest, fatigue, relative acuity of the eyes, etc. While the amount and character of replacement is controlled by attention, and while the directing of attention is a voluntarily controllable mental act, the replacement process is not itself under voluntary control. Experiments indicating that the binocular image has a

slightly greater intensity than that of the monocular may be interpreted, according to Verhoeff, as meaning that the conscious image, generally, is contributed by those portions of each monocular image having the higher intensities; its intensity would therefore usually be above the mean intensity of the monocular images. When retinal images are duplicates, the conscious image will have a value identical with that of either monocular image. When the images differ in some features, attention fluctuates accordingly and the proportions of replacement are thereby determined.

**Visual Perception, Its Anatomy and Pathology.** The effect of destruction of cortical tissue in the visual sensory areas was mentioned earlier in this chapter. Loss of vision results, the amount and character of such loss being determined by the size and location of the lesions. Unilateral injuries result in losses affecting the visual field of the opposite side; if extensive enough, vision for objects in the entire opposite half of the field will be abolished. Bilateral lesions affect both sides of the visual field. If the lesions are small and localized, small areas of blindness result which are of the same form for the field of each eye.[65] Such cases merely illustrate the facts stated regarding the fiber relations between the retinas and the brain.* Much of our knowledge of these relations has come out of clinical observations. Clear evidence is sometimes presented by restricted lesions resulting from accidents. Holmes and Lister reported a case, for example, in which there was total loss of central vision with sparing of peripheral vision as a result of a wound which destroyed the tip of each occipital lobe.[66] Injuries owing to cortical destruction by disease do not always, however, furnish satisfactory evidence. As Holmes says, "Clinical investigations designed to throw light on normal functions . . . present more

*There appears to be good evidence for the view that the macular area of each eye is projected upon *both* sides of the visual cortex. A number of cases have been reported of homonymous hemianopsia (blindness of symmetrical or corresponding halves of the visual field) owing to injury to one of the occipital lobes, in which central vision was not affected. Removal of all of the striate area of one side appears to be possible without injury to macular vision. Penfield, Evans and MacMillan[67] suggest that there may be optic nerve fibers from the maculas which pass to the visual cortex of the *opposite* cerebral hemisphere, i.e., e.g., from the left halves of the maculas to the right visual cortex, as well as to the left visual cortex. Collateral branches are given off from the optic radiation (geniculo-calcarine paths), they suggest, which pass via the splenium to the opposite side.

difficult problems than those of the laboratories, for the clinician must accept the conditions as they occur; he cannot arrange for them to happen as the experimentalist may do, nor can he at will repeat the experiment which disease has performed."[68]

There is much evidence, however, in support of the view that the cortical centers of the occipital lobe adjacent to and surrounding the area striata are the primary seat of the processes whereby things seen are *recognized* or identified. These centers are located mainly on the outer surfaces or convexities of the occipital lobes.[69] They are connected with the striate areas by association fibers. The evidence indicates that impulses are relayed to these neighboring centers, and it is here that the higher mental operations take place which underlie the perception or understanding of visual impressions, e.g., the identification and naming of common objects, and of persons; ability to read; ability to imagine things in visual form.[70, 71] Loss of such abilities, with retention of vision, is variously called psychic blindness, mind blindness, visual agnosia, visual imperception.*

Head describes a case which clearly illustrates the fundamental features of mind blindness.[72] The patient, who exhibited these symptoms for six years, unquestionably was able to see, but showed profound disorders of visual perception. She was aware of the size, form and brightness of objects, and avoided them when placed in her way, but was unable to tell what they were. She was unable to recognize individuals by sight, but was able to identify a number of people immediately by the sounds of their voices, peculiarities of gait, gesture and manner. (Distinctive movements, it appears, aroused associations, but the visual pattern of the features did not.) Ability to name objects and colors suffered most. She could at times indicate a visible object by words describing its use, but was unable to give its name until it was put in her hands (tactual perception). She could write, and take dictation, but was unable to read what she had written, though she could sometimes recognize words by making the finger movements of copying them

*Warren (Dictionary of Psychology, Houghton Mifflin Co. 1934) defines psychic blindness as inability to see resulting from impairment of the cerebral cortex, but suggests the term be limited to psychogenic (hysterical) inabilities to see. Mind blindness is then defined as ability to see accompanied by loss of ability to understand or interpret what is seen.

Perception of tastes, odors and sounds was unaffected; e.g., a lemon was recognized by its odor, bread by its taste, a watch by its ticking. An object seen, recognized by touch, and seen again shortly afterward was not even visually familiar, the previous visual impression having faded too quickly. There was marked variation in perceptual capacity from day to day. At times the patient could recognize a number of familiar objects at sight; again, none were identifiable. The symptoms followed upon a "stroke"; post-mortem examination showed degeneration of the tissue of the occipital lobes and sclerosis of the cerebral arteries.

In a summary of the characteristics of these cases Head finds the main symptom to be a loss, more or less profound, and fluctuating markedly in the same person, of the capacity for visual perception of the identity and use of objects. Reading ability was defective or absent in 21 of 22 cases. Ability to speak and write was often disturbed. Mental apathy, diminution of cerebral activity, was manifested. The visual defect rarely occurs in isolation from other mental disturbances. In most cases the cortical lesion affected both hemispheres, was widespread and associated with extensive degeneration of the arterial system.

A specific form of mind blindness affecting the ability to read and known as *alexia* is a result of injury to the angular gyrus (convolution) of the left hemisphere (Figure 4). Fibers converge upon this area from the calcarine areas of both sides, those from the right side passing over by way of the corpus callosum.[78] One of the cases reported by Nielson and Von Hagen was unable to read but could recognize words if traced with the fingers. Visual word imagery was not lost; the patient wrote by visualizing letters and copying the images. A second case reported by the same writers was similar in this respect, inability to read being accompanied by ability to write and to visualize. The defect was attributed to softening of the cortical tissue under the left angular gyrus and of fibers connected with this region. While alexia and general mind blindness are frequently associated, reading ability is not always affected in the latter cases. It is, however, often accompanied by partial or total loss of vision on the right side of the field when the lesion

involves the fibers (optic radiation) coursing toward the area striata.[74, 75]

Mind blindness has been found in animals as well as in man. A dog suffering from this defect, for example, can see objects and avoid them in moving about but shows no signs of recognizing their character. The animal does not respond to the sight of food, is unmoved by threats with a whip. Such a disorder is produced by means of bilateral destruction of tissues neighboring on the primary visual area.

Mind blindness may affect other aspects of visual perception.[76] In one case the symptoms resulted from a coagulation of blood in a cerebral artery (thrombosis). There was hemianopsia and a temporary loss of ability to recognize objects and people. For a period of two months the patient manifested, in addition, a loss of spatial orientation. He was without any sense of direction and of the location of familiar landmarks about his home. He did not know the direction of the street where his home was situated, nor how to get to a place a few blocks away.

A peculiar form of mind blindness probably involving a higher level of the perceptual process exhibits a loss of ability to grasp the significance of visual patterns as wholes, though the individual parts may be recognized. In one case[77] the patient could identify several of the elements of a picture but could not make out the meaning of the total. After studying a picture of a man telephoning he was able to describe the face and recognized the transmitter, but was unable to combine these items with any certainty into the percept of a-man-telephoning. When shown a picture of a horse and rider, both struggling to regain their feet after a fall, he recognized the head, feet and tail of the horse, the head and body of the rider, but was able to form no idea of the incident depicted; finally he guessed that the man might be riding on the horse. He reacted in a similar fashion to other pictures. He was also spatially disoriented and had lost the capacity to visualize his home, familiar objects and scenes. The defect of perceptual synthesis is attributed by the investigators to bilateral lesions in the precuneus convolution and in the upper portion of the left cuneus (near the top of the occipital lobe). The spatial disorganization is traced to softening of the under surface of the left occipital lobe. It

has been suggested[78] that, in general, the farther an adjacent cortical area is from a primary sensory center, the more synthetic or elaborative its function in relation to that center.

Of the three cases of mind blindness reported by Nielsen and Von Hagen, one was the result of softening of the occipital tissue as a consequence of a coagulation of blood; one resulted from encephalitis (inflammation of the brain) associated with softening; the symptoms in the third case followed the use of sedatives (allonal and sodium bromide) and disappeared upon their removal. Cerebral tumors may also cause such disorders.

A distinctive type of perceptual defect in the language sphere is known as *congenital* word blindness and represents, not the *loss of ability to read, but a deficient capacity to acquire this* ability, dating from an early age. It has been estimated that approximately one of every two thousand children exhibit this defect.[79] Cerebral pathology is not indicated in these cases. McCready[80] suggests damage at birth (cerebral hemorrhage), but cites evidence that the trait may be hereditary, a "biological variation." In one instance reported the mother had never been able to learn to read and testified that five other children in the family exhibited the same defect. McCready mentions four cases in three generations of one family; four cases in two generations; and several other instances affecting persons related by blood. The deficiency appears in persons of normal and even superior intelligence,[81] expressing in very marked retardation in learning to read lasting until late childhood, and at times may be permanent.[82]

According to Warren's restricted definition of *psychic blindness,* the term applies to a loss of vision in which there are no organic lesions as a physical basis of the disorder. The various forms of hysterical blindness fall under this heading. Both motor and sensory disturbances of vision may be of this character. The concepts of *suggestibility* and *dissociation* are involved here; the symptoms are closely related to certain phenomena of hypnosis.[83, 84, 85]

## NON-VISUAL OCULAR SENSATIONS AND THEIR FUNCTION

Later chapters will supply many illustrations of the statement that there are numerous features of what appears to be

visual experience which cannot be explained altogether by retinal stimulation. The visual function in its broadest sense includes, in fact, a cooperative integration of a number of reaction systems whose processes affect both its sensory and motor sides, and among which are the muscles of the eyes and neck; the semicircular canals and the utricle and saccule of the internal ear; the selective activity of attention; and finally and perhaps most vitally, the mental processes which may be generally designated as associative memory. The last two factors will be discussed in subsequent chapters. The present section will deal briefly with the place of ocular muscle sensations in visual experience.

A few simple observations may be mentioned at outset to show the necessity of finding certain non-visual sources of sensory information whose existence is needed to supplement the data of vision proper, in order to satisfactorily account for visual experiences in their concrete forms. When we fixate the eyes on a stationary object, for example, its image remains motionless on the maculas and we perceive the object as stationary. In following a moving object by a corresponding movement of the eyes we again maintain the object in a stationary or very nearly stationary position on the maculas, yet here the perception is of an object in motion. The percept will be the same with the eyes fixed while a proper rotation of the head serves to maintain a macular position of the image. Again, in fixating, with the head held upright, a tree trunk whose image approximately coincides with the vertical meridian of the retina, we perceive the tree as vertical; yet with the head inclined to one side and the image therefore obliquely located with relation to the same meridian, the tree is still perceived as vertical despite the change in retinal stimulation. It might be supposed that this stability of the perceptual impression would result from experience,—the knowledge that all trees are normally vertical or nearly so, but the same demonstration might be made in the absence of such foreknowledge.

Another instance is offered by the study of *after-images.* If a piece of colored paper is fixated for a few seconds and the eyes then transferred to some uniform neutral surface, e.g., a sheet of grey paper or a nearby wall, a patch of color will be

observed. This visual impression is, assumedly, the result of a persistence of the activity aroused in the retina by the preceding stimulation, the after-image being the external projection of the retinal image. The retinal location of this image is constant (i.e., the distribution of the individual receptor processes remains fixed) but the position of the projected visual image moves about as the eyes are moved over the fixation surface. The location of the image is determined by the position of the eyes.

If the eyeballs are rotated, not by contraction of the ocular muscles, but by pressure of the fingers,—"passive" rather than active rotation, the position of the after-image does not change. Finally, when the eyes are moved over stationary objects, no impression of object-movement results from the movement of their images here and there upon the retina, but if one eye be closed and the other moved by finger pressure, an apparent movement of all objects occurs. Obviously such facts as to the visual impressions of location and movement of objects cannot be accounted for by reference to the location and movement of the retinal activity set up by stimulation. Additional factors are implied.

*Kinesthesis.* It has long been known that muscle movement is a source of sensation. Sense-organs in the form of nerve endings wound spirally about the muscle fibers (Figure 16), and whose stimulus is supplied by muscle contraction, are the structural source of these so called *kinesthetic* sensations,—meaning sensations of movement. Similar sense organs are found in the tendons and joints, and while together they supply the above-named sensations, the term will be used here to refer to the muscle sensations alone.

In general these receptors imbedded in the muscles are the largest and perhaps the most important group of sense organs located within the body, each individual muscle fiber having its spindle of sensory nerve endings.[30] The sensations arising from muscle movement are independent of those of the touch sense, as can be demonstrated by anesthetizing the skin locally, and by the fact that in certain diseases (locomotor ataxia) the sensory fibers for kinesthetic impulses are destroyed, leaving those for touch intact. It is also demonstrable that a difference between

two weights can be more accurately discriminated when the weights are "hefted," involving flexion of the muscles, than by the mere difference in passive pressure when the weights are laid upon the palm of the hand. It is observed, moreover, that the coordination of muscle movement is greatly disturbed when

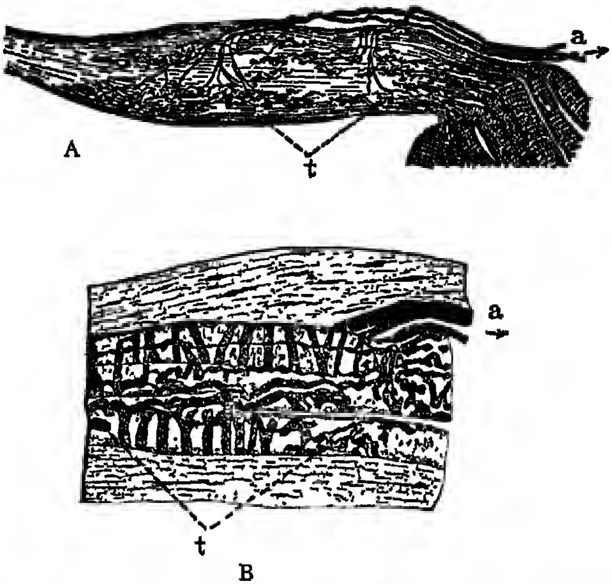


*Fig. 16.* Receptors in muscles and tendons. A. Nerve endings attached to a tendon. B. Nerve endings wound about muscle fibers a, axons, t, terminals. (From Freeman, Introduction to Physiological Psychology, The Ronald Press Co.)

the kinesthetic nerves are destroyed (as in the disease mentioned above), and relatively very little following the loss of touch sensations alone.

The kinesthetic sense is our most vital source of information of the position and movement of our limbs; by its means we are instantly able to tell, e.g., when in the dark and in the absence of contact with any object, the exact position of our hands or the character of any movement we are making with them. More practically, the function of kinesthesis is well seen in almost any well coordinated motor performance in which familiarity with the proper "feel" of an act is a highly important factor in ensuring its successful guidance and completion. This factor is

clearly seen in so called "touch" typing and piano playing, where much of the performance may be carried on without the use of the eyes, and where touch sensations are aroused only *after* the proper keys have been reached and struck. An accurate and continuous supply of information as to the position and rate of movement of the limbs is essential to the skillful coordination of any motor activity. To the extent to which such coordinations take place in the absence of vision, or, as in the case of rapid piano playing, where the eyes alone are incapable of supplying the requisite cues, kinesthesis is the main and often the only channel by which this knowledge can come.

**Ocular kinesthesis.** The part played by muscle sensations in visual experience may be introduced with a few of the simple observations made by Sherrington.[87] Three spots are placed in a vertical line on a flat screen directly in front of the observer, and viewed with the right eye, the middle of the three spots being fixated. The images of the spots fall upon the vertical meridian of the retina, and the spots are *perceived* as located in a vertical line on the screen. A second screen, also with three vertically placed spots, is then put up above and to the right of the first; it is set at right angles to the line of (oblique) vision, and the middle one of the three spots is similarly fixated, with the head stationary. Now it is known that in such oblique movements of the eyes, e.g., upward and to the right, the eyeball tilts in its rolling in such a way that the vertical meridian of the retina does not remain exactly in the vertical but inclines a bit away from it. The upper part of this meridian shifts toward the right, the lower part toward the left. In consequence, with the second fixation, the row of dots will not fall upon the vertical meridian—now no longer truly vertical—but will be slightly inclined in relation to it. The significant fact is that the three spots are now still *perceived* as located in a vertical line, despite the shift in the location of their retinal images.

The explanation of this fact, according to Sherrington, is that the mind reacts, not to the retinal impression alone, but to a combination of the retinal impression with sensations from the ocular muscles. The muscle sensations from the eyes in the second position compensate, in effect, for the displacement

of the retinal images, and inform us that the images are still in the vertical. Or, to put the matter differently, the kinesthetic sensations from the second posture of the eyes cause us to "make allowance," perceptually, for the change in eye position which displaces the images, and thus to continue to see the spots located as they really are.

The point may be further illustrated. Suppose that the spots on the second screen are brightly colored and are fixated long enough for an after-image to develop. This means that the areas on the retina aroused to activity by the stimulation will continue active for a period, and thus we continue to see the images. (It will be recalled that while the color spots are seen as vertical, their images do not fall upon the vertical meridian in the secondary position.) The eye is now rotated back to the first position and the middle spot of the vertical points is again fixated. The after-images of the three spots are now seen in a line which is inclined in relation to the original set of vertical spots, which now coincide with the vertical meridian of the retina. Their present diagonal position results from the fact that the retina was not quite "upright" during the second fixation. Since the areas of retinal activity excited do not change their position as the eyes return to the first position, the after-images will necessarily be seen in an oblique line. The important fact is that without any change in the location of the active retinal areas (i.e., in effect, the location of retinal stimulation), the spots are seen in the vertical in one position, and inclined to the vertical in the other. Since the only ocular change which has accompanied this change in perception is the posture of the eyes, the conclusion, here as before, is that the mind reacts to a combination of the retinal impression with postural sensation (kinesthesis). Our perception of the visual position of objects, in all oblique movements of the eyes, must be corrected for the displacement of the image on the retina, and the character of the correction required is indicated to us by the kinesthetic sensations associated with these movements.

A similar instance may be observed when the head itself is tilted in viewing a vertical object. The perception of the vertical position of the object is unchanged, although the image

may be markedly shifted away from the vertical. Here the kinesthetic sensations arise from the neck muscles, and are reënforced by sensations from the organs of the internal ear which inform us of our own position.[58] A simple analogy involving the postural factor in space perception is offered by Sherrington. If three points are stimulated on the hand when it is held horizontally, the line of points is perceived as horizontal in position. When the same points are stimulated with the hand held vertically, the perception is of vertical position. Since the local tactual stimulation is identical the difference in perception must be a consequence of the difference in muscle sensations from the two postures of the arm.*

**Visual Projection.** With the eyes and head stationary, a luminous object exposed at different positions in a dark room casts its image upon correspondingly different retinal areas. Visual consciousness of the location of the object will vary with the retinal location of the image, and will be wholly determined by this factor. If the location of the image is changed by placing a prism in the path of the light rays, the apparent location of the object may be varied at will, though its actual location remains constant. The retinal position of the image is therefore the sole determinant, in this instance, of the visual direction sense, and since different image-positions represent the stimulation of retinal receptors whose fibers are distributed in a definite order upon the optical cortex, an anatomical basis is provided for the observed sensory data.

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*Irvine and Ludvigh,[59] in a critical analysis of Sherrington's observations, point out that an alternative interpretation of the data described is possible. The fact that the percept of the "verticality" of the two sets of spots remains constant despite the shift of retinal images does not necessarily involve the kinesthetic factor. With an unmoving eye, different retinal images may arouse the same percept, as when a circular plate is perceived as circular whether the retinal image has a circular form or whether, owing to perspective distortion, the image is elliptical. Numerous examples of the same phenomenon will be described in the chapter following, where the interpretation in terms of past experience will be set forth. The writers repeated Sherrington's experiment with after-images and moved the eye to the secondary position passively, by forceps applied to the conjunctiva. No movement of the after-images was observed (cf. Carr,[60] p. 176). They believe some movement should have resulted if the kinesthetic sense is as sensitive as Sherrington believed, unless the kinesthetic receptors of the extrinsics do not respond to passive movement. The existence of kinesthetic nerves from the extrinsic muscles is an inference, they assert, rather than an anatomically demonstrable fact.

If, with head and body stationary, the image of the object in its various positions is fixed upon the macula, the retinal factor becomes a constant, and knowledge of the location of the object must be mediated by the position of the eyes. Movements of the object, assuming continuous fixation, will be made known by the amount and direction of the ocular movement required to maintain fixation, and the channel whereby this information comes must be kinesthetic. Experiment has demonstrated that the direction in which the eyes are pointed may be accurately judged in a dark room in the absence of any visual cues and with the front of the eyeball and the inner surface of the lids anesthetized by cocaine. It thus appears that the direction of fixation and therefore of the object fixated may be properly judged on the basis of the sensations provided by ocular movement and position. The knowledge of direction furnished in this manner, moreover, will be identical with that given by the retinal position of the image with the eye stationary. That is, the effect of kinesthetic impressions is such that the object is projected—with respect to direction—in the same manner as it would have been had the eye not moved at all, and direction had been judged on the basis of position of the retinal image alone.[90]

If we regard each eye as acting by itself, the direction of any object will be simply determined by the character of the movement, up or down, right or left, required to fixate it. We would not, however, on the basis of the monocular kinesthetic impressions, know *where* on the line of fixation the object was located, i.e., how *distant* the object, since the muscle effort and therefore the muscle sensation will be the same whatever the distance, for the same direction. When both eyes are used, on the other hand, in converging upon a near object located midway between the eyes, the muscle effort will be equal for each eye, and since this effort will increase or decrease as the object approaches or recedes, respectively, the corresponding amounts of muscle sensation resulting will be an index of the distance of the object, and the equality of such sensation as between the two eyes will be a sign of midline location. If fixation is upon a near object to one side of the midline, con-

vergent and conjugate movements will combine; the amount of the former will mediate distance; of the latter, direction.[91]

Regarding a single eye, as stated before, kinesthetic sensation provides a judgment of direction which is the same as that given by image location in a stationary eye. In case of binocular fixation the situation is the same, except that the mid-point between the eyes becomes the point of reference, rather than, as with monocular projection, the visual axis of the single eye. This means that binocular projection takes place in the same manner as would the monocular form if each eye were displaced to a midway position and then, motionless, projected according to image location.[92]

The discussion of visual distance judgments will be resumed in Chapter V, where a number of important factors concerned in such perceptions will be studied. The place of kinesthetic impressions in vision will be touched upon again, and experimental evidence of the efficacy of ocular movements in mediating distance consciousness will be described.

## Chapter IV

# VISUAL PERCEPTION

Preceding pages have outlined the visual reaction system with the emphasis on its stimulus-response relationships and its physiological foundations. The present chapter introduces the more properly psychological sections of study, moving away from neural pathways and processes for the main discussion, and into the more familiar field of conscious visual activities as they are concretely experienced. For the most part these will deal with the receiving, sensory or "intake" side of vision, embracing the immediate mental consequences of retinal stimulation, and an analysis of what it is that the mind adds to the retinal recordings for the composition of visual impressions in the form in which we directly know them. The present chapter and those following on "Space Perception," "Visual Sensations," and "Visual Illusions" deal with this aspect of vision. The chapter on "Attention in Relation to Vision," while emphasizing the sensory aspect, includes a brief discussion of the relations between mental states and the motor side of vision,—the character of the influence of different mental attitudes on the refined muscular adjustments involved in seeing.

. . . . . .

On the surface nothing might seem more obvious than the statement that visual experience—what we see—depends upon the way in which the visual receptor is stimulated. An object is seen as red or as blue, depending on whether the light which strikes the retina is of long or short wave length. It is seen as large when the amount of retinal surface stimulated is large. It is seen as a circle or as a rectangle because the area of retinal stimulation is circular or rectangular in form. Similarly a sound of high pitch is heard when the tympanum or ear-drum is set into rapid vibrations by correspondingly rapidly beating

air waves; a low-pitched tone is heard when the vibration rate is slow. The sound is loud when the waves strike forcefully; soft when their impact is weak. Other features of sound quality are referred to the physical complexity of the stimulation, i.e., the amount of mixture of the fundamental wave-frequency with other frequencies. Less is known of detailed stimulus-response relationships in the case of such senses as taste and smell, for example, but theoretically such relationships must exist. It would appear, then, that the various qualities and forms of experience are attributable to the particular character of receptor activity; in case of vision to the plain facts of retinal stimulation.

A little reflection, however, shows clearly that no such simple relation between experience and stimulation exists, that what we "see" actually fails to check with what the retina supplies, and this in a large variety of instances. Many of these are familiar in the literature of psychology. A glance at the table at which I am sitting, for example, instantly tells me that it is circular in form, but obviously it could not throw a circular image upon my retina unless I were somehow poised directly over it and looking down upon it, or unless it were to be tilted over at right angles to my line of vision. The retinal figure, from a sitting position, is elliptical in form; as I move away from the table this ellipse becomes flatter; at a greater distance the figure will approach a horizontal line. Whatever the point of view, however, I will continue to "see" the table as circular. If the table happened to be a square one I would perceive it as square, though a moment's thought would suffice to convince me that my retinal image of it could not be a square if my line of vision is at anything less than a right angle to the plane of the table top. Usually the image must be a four-sided figure with two acute and two obtuse angles, and with two of the sides, corresponding to the nearer sides of the table, longer than the opposite two. A vast number of retinal images are in this way distortions of the forms of the objects they register.

Looking down a street at a row of houses I observe that the architecture is similar and that all of the houses are of approximately the same size; yet the retinal image of the most distant house may be only a half or a third the size of that of the nearest house. I perceive correctly, however, in spite of the

diminished images. As a man approaches me from a distance of ten yards to one of five, my image of his height doubles and of his breadth likewise, the image as a whole increasing four times in size. All the while I perceive only a man of a certain constant size walking toward me. If two cardboard rectangles, one measuring two by three inches, the other six by nine inches, are placed, the smaller at a distance of one yard, the larger at three yards, they will cast images of equal area; yet one will be perceived as much larger than the other.[93] Visual experience here checks with objective fact rather than with retinal data. The perceived size-difference overrides, as it were, the dimensional identity of the images.

The same fact may be observed in the case of motion. "When I am ten yards away from the moving object, retinal speed will be one-half of what it is at a distance of five yards. In direct experience, however, there is no appreciable difference of speed between the two cases of movements."[94] The image of a nearer object may pass across the sensory surface at double the speed of the image of a farther object, yet both are visually perceived as traveling at the same rate: again a disharmony between what the receptor records and what experience reports. Many writers have commented on the perceived constancy of the brightness of objects under changing illumination. It has been computed that the intensity of sunlight is some 800,000 times that of moonlight, yet a white house, for example, will be seen as "white" under either lighting. A white object seen in deep shadow will be identified as white; a black object under high illumination is seen as black, though the latter may reflect more light to the eyes than the former. Interesting examples of similar phenomena have been observed in the field of color experience. "For three consecutive evenings I have had this happen. I have come home from the campus when it was too late for colors to be seen, but when the outlines of familiar objects were perceptible. As I turn a certain corner I recognize a grove of pine trees, and I see the green of these trees. It is a fairly good green, but darker than that which these same trees have when I see them in the morning. Then I realize how dark it is and become critical toward these trees, and I find them to be a very dark grey with no trace or hint of green."[95]

Generally we tend to see objects "as they really are" or as we have, in the past and in various ways, learned that they are, rather than as they appear at any given moment in the innumerable changing visual aspects resulting from variations in distance, position and illumination.* "A 'thing' which we follow with the eyes . . . will change its retinal image incessantly. A cross, a ring, waved about in the air, will pass through every conceivable angular and elliptical form. All the while, however, as we look at them, we hold fast to the perception of their 'real' shape by mentally combining the pictures momentarily received with the notion of peculiar positions in space. It is not the cross and ring pure and simple which we perceive, but the cross *so held*, the ring *so held*. From the day of our birth we have sought every hour of our lives to *correct* the apparent form of things and translate it into the real form by keeping note of the way they are placed or held. In no other class of sensations does this incessant correction occur."[60]

It is very far from true, then, that retinal stimulation alone furnishes us with visual information in its experienced forms. Even so elementary a fact as the depth or front to back extension of objects cannot be conveyed to the mind, it would seem, by the sensory surface, for this surface, in the case of the retina, is two-dimensional, so that only two-dimensional images are possible. None the less we "see" the third dimension of objects as simply and immediately as we see their color and their size. The same point is still more obviously apparent in the experiences described or implied in such statements as "The street looks wet," "The chair looks heavy," or "The fabric looks soft," etc. The term "looks" suggests that these touch and kinesthetic qualities are visually received, and here again the retina, of course, could hardly be the source of the impressions. Enough has been said to show clearly the many instances in which retinal

*References hereafter to objects "as they are" will signify merely our sensory impressions of them under usual or normal conditions. Thus the "true" color or brightness of an object will mean its color or brightness in daylight illumination. The retinal or sensory impression of an object *perceived* as circular (as a table top) may, however—owing to constant perspective distortion—rarely be itself circular in form. The "usual or normal" impression in this case will not be that of the "true" form. The percept of circularity will be fairly consistently aroused by an elliptical image as its sign. This percept is, nevertheless, confirmed by handling the object, and the visual image usually approaches the circular form when we do this. The object, moreover, is socially referred to as "round," which helps to standardize that one of its various forms as the "true" one.

stimulation does not check with visual experience or in which the retina appears to be anatomically incapable of supplying it.

## THE FORMATION OF PERCEPTS

The reason for this lack of correspondence will doubtless have been glimpsed in the last illustration offered. Here the concept of association or conditioning may be simply applied. Some time in the past I have handled this fabric or others like it, or "hefted" this chair or others resembling it, and now "associate" the previous touch and muscle impressions with the present visual impressions. The retina supplies the latter; the remainder of the experience is furnished by memory. The reaction therefore consists of a combination of visual sensation and memory, and it is such a reaction that we designate by the term perception. To explain the development of a perception it is necessary to find the origin of the memory and to discover how it came to be attached to the sensation. In the above instances the memories are clearly derived from earlier sensations and may be considered as faint reproductions of those sensations. These memories are associated with the present visual sensation, then, because the original touch experiences were once received simultaneously with the visual, the circumstance, it will be recalled, under which reactions become "conditioned." "While we respond to contact with the object, other stimuli from the same object frequently act upon us. While seeing an object we may also smell it. While smelling it we may also hear it. Thus, each stimulus may finally call forth, by conditioning, any of the responses that any of the other stimuli would naturally provoke. In this sense we may say that an adult responds to an object as a whole."[97]—The "whole" consisting of consciousness of all of its various qualities, some of which are received by direct sensory stimulation, others being the recollections of previous sensory stimulation. This latter portion of the total reaction may be so closely combined with the sensory elements as to be indistinguishable from them. The softness of the fabric seems like a direct visual experience. "A firecracker never looks the same to the baby after one has exploded in his fingers."[98]

We may define a visual sensation as consisting of consciousness of qualities of an object when that consciousness is the direct

result of sense organ activity. Only those data which are so derived will be called sensations. The hearing of a sound of a certain pitch and loudness would be an auditory sensation; the recognition of it as a clock-chime involves more than sheer sensation, for we once had to learn the source of such a sound. A new-born infant would be likewise conscious of pitch and loudness but there his experience would end. These auditory qualities will not be associated with a clock, will not suggest, stand for, or *mean* a clock, for as yet the infant has never seen one, or at least has never traced the sound to this object. Similarly a fire may "look" hot at a distance through an association of the thought of heat with a characteristic visual impression of luminosity, but it will not have this "look" for the infant in advance of an actual experiencing of heat through contact or proximity, whereby the association may be formed. Visual perception we will therefore define as consciousness of qualities of an object directly resulting from retinal stimulation, and in addition, consciousness of qualities or characteristics which are *not*, at the moment, the result of the stimulation of *any* sensory surface. The latter components of the perceptual experience are memories rooted in previous more intimate, i.e., sensory, contacts with the same or similar objects.

By this formula, accordingly, and using the term "sense" as the verbal form of sensation, we may say that we *sense* sounds of various pitches, intensities and mixtures, and *perceive* clock-chimes, auto-horns, voices, etc. We visually sense the characteristic closely-knit texture of silk or satin and perceive its softness; we sense the glistening surface of the street and perceive its wetness. The infant receives the visual impression of a peculiar distortion of its mother's features and later perceives or recognizes this sensory pattern as fear, joy, irritation, etc. It must learn the meanings of such visual patterns just as it must learn the meanings of words. It may be emphasized again, finally, that every perceptual reaction has a sensory component. Simply, the perceptual reaction is a larger activity. The "mind" adds its contribution to the information furnished by the receptor.

In these examples, it will be noticed, it is a particular item, feature or aspect of the whole object which evokes the response called a perception. It is the distinctive visual texture of the

fabric which educes the consciousness of its softness; the sheen or glisten of the street that arouses the percept of its wetness. These items of the total visual form or pattern of objects which specifically incite perceptual reactions will hereafter be called *signs*. That stimulus or portion of a stimulus which calls forth a percept is a sign. An infant responds to many stimuli, but few of these are signs because there are so few memory associates, at this stage, connected with the sensory responses. Memories, we know, are the remnants of experience and therefore cannot exist before experience has begun. The term "meaning," further, will henceforth be used as a collective name for the memory associates whose combination with sensory impressions (e.g., the visual image) composes a percept. Thus the reddish glow of a piece of metal *means* heat; the granular surface appearance of sandpaper means or signifies tactual harshness. It follows that the more experience we have had with an object the more memories we will associate with it, and the more meanings, in consequence, it will have for us.

Likewise the same object will mean different things to different people, will be variously perceived by them, reflecting the quality of their experiences with it. Or an object may change its meaning for the same person following new experiences. We may infer that a child who shrinks from a candle-flame has a percept of it quite unlike that of a child who reaches toward it; that a boy who avoids a particular dog does not perceive it in the same way as another who calls it to him. In either case we assume unlike experiences with these objects as the basis of their different meanings. Since the manner in which we deal with things or behave toward them is determined by their meanings for us, our objective behavior becomes a fairly reliable index of the character of our percepts.

## RECALL IN PERCEPTION

The analysis of visual perception into visual sensation in combination with recalled experience requires a few remarks concerning the type of recall which occurs in these instances, since from one point of view it is markedly different from ordinary recall. When someone asks us for the name of a little known individual, for the address of a friend or the phone number of a relative, we are often aware of a moment of concentration in the effort to recall the information wanted, and of a fairly

definite interval between the reception of the stimulus to recall and the arrival in consciousness of the recalled item. A characteristic feature of recall in the usual sense is this introspectively noticeable time interval. Less frequently, perhaps, but often enough, this interval is filled by the feeling of effort. We are, as we say, "trying to remember." Perceptual recall, by contrast, is distinguished by the absence of this interval and this effort. Earlier in the text reactions were considered which, though originally learned with effort, delay and deliberation, had finally become automatic and immediate by reason of many repetitions. Such involuntary acts become distinguishable from true reflexes only on the basis of their acquired character. Applying this habit concept to the "mental" type of reaction termed recall, the same results would be anticipated, and this is what is found to be true of the kind of remembering that takes place in percepts. These reactions might be characterized as "memory automatisms," so completely without delay and so entirely without volition do they take place.

A further and rather striking feature develops out of this process of combination. So very nearly instantaneously does memory rise to consciousness, following upon the sensory part of the reaction, that the two components of the percept merge or fuse into a single conscious whole and lose altogether their separate identities. The two reactions are experienced as one, undergoing a synthesis comparable to a chemical combination in which two substances vanish and a new one with unique properties emerges from the fusion, as in the combination of gases to produce a liquid. The analogy was popular with the older writers. However the union be described, it is so intimate as to confer, in effect, non-visual qualities upon visual impressions. We do seem to "see" the heat radiating from a red-hot casting, or the pressure of the wind against trees in an approaching storm. The surface of the water of a pool has an unresisting "look." Certainly there are differences between the *visual* impressions of a brick pavement and a golf green, or between those of burlap and black "pony fur," for example, which are strongly suggestive of the qualities of touch. There are many illustrations of such inter-sensory blends.

Language reactions provide clear examples. The meanings of spoken words are experienced as of the very essence of their

sounds; we seem to *hear* the meanings themselves. Yet those who have mastered a foreign tongue can testify that there was a time when the hearing of a foreign word and the recall of its meaning, or the seeing of such a word and the thought of its meaning, were two quite separate events, and when the effort and the delay of recall made reading or auditory comprehension a very slow and laborious process. Gradually, with practice, the delay diminishes along with the effort, and finally meaning becomes an integral and inseparable part of the word forms and word sounds themselves. Skilled introspectionists have detected changes in the very sound-quality of words as their meanings blend with them under certain conditions. "Verbal sounds are usually perceived with their meaning at the moment of being heard. Sometimes, however, the associative radiations are inhibited for a few moments (the mind being preoccupied with other thoughts) whilst the words linger on the ear as mere echoes of acoustic sensations. Then, usually, their interpretation suddenly occurs. But at that moment one may often surprise a change in the very *feel* of the word."[99] This fact may easily be demonstrated by the process of fatiguing recall until meaning dissolves away from a word-sound. The repetition of a familiar word, aloud or to oneself, several dozen times, will finally cause it to assume a strange "feel" as its meaning gradually becomes dissociated.*

The recall that takes place in perceptual response is therefore unlike "ordinary" recall. Because of its speed and the auto-

*The same phenomenon in the case of visual perception of words has been described by Severance and Washburn (The Lose of Associative Power in Words After Long Fixation, Amer. Jour. Psychol. 1907, 18, 182-186). Words were steadily fixated until in some cases even the individual letters became meaningless. Stages in the loss of associative arousal were reported. First the meaning and the sound image of the word vanished, the visual pattern of the word as a whole remaining familiar. Then this pattern lost its familiarity and became a mere collection of letters; finally the letters themselves became unfamiliar, the word appearing simply as a group of strange figures on the paper. Following the disappearance of normal meaning and sound associates others might be suggested by syllables and fragments of the word which became momentarily prominent owing to the shifting of attention. The letters often tended to fall into smaller groups after the sound image of the whole disappeared, and this in turn led to a loss of the visual familiarity of the whole. The investigators find the connection between the sound of a word and its meaning to be much closer than that between its meaning and its visual appearance. The spoken language is learned earlier and used oftener than the written.

matic manner of its occurrence it is not introspectively identifiable *as* recall. Because of the instantaneous fusion of elements the recalled qualities appear in experience to be directly given as *sensory* impressions. So effortlessly, smoothly and quickly does the mind blend its contribution with the data supplied by the receptor that we are deceived, as it were, into assuming that this contribution must itself have been a product of receptor activity, for these memory supplements may be no less vivid than sensations in their impact upon the mind.[100] So we see, or rather seem to see, many things which the eye is structurally and functionally incapable of furnishing. In many cases such experiences therefore amount to visual illusions.

This analysis of the percept cannot, therefore, be confirmed by direct introspection.* Such an attempt destroys by its own activity the integrity of the process it seeks to examine, just as it tends to destroy an emotion by unavoidably turning the attention away from the stimuli that arouse it.[101] Indirectly, however, such an analysis may be made. The repetition of a word, as was mentioned above, may finally cause it to sound strangely to our ears. The meaning portion of the percept is little by little sloughed off—probably by cortical fatigue—leaving behind only the naked sound-skeleton of the word,—its bare sensory form. The "feeling" of the word would here tend, assumedly, to approach that which it would have for a person unfamiliar with the language. Early in life, of course,

* Percepts vary in the degree of their integration. In certain cases the separation of sensory and perceptual reactions may be partially effected without difficulty. The motion of two objects, for example, travelling at the same speed at different distances from the observer, may be perceived in accordance with the objective facts, the two motions being apprehended as equal. By fixing the attention differently, however, a motion impression expressing the actual difference in rate of passage of the images across the visual field may be obtained. The sensory and perceptual impressions may thus be contrasted. Similarly the apparent size differences (owing to distance) between the images of objects perceptually grasped as equal in magnitude may be observed without effort. It is said to be possible, by properly setting the attention, to effect this separation in the case of an approaching object, i.e., the object may be seen as constant in size but moving nearer, or as expanding in size at a fixed distance. Owing to habit and the potency of distance signs, in the latter case, this "reduction to sensation" is very difficult to achieve. The reduction of a percept by a voluntary setting of attitude (involving the attentional exclusion of signs), as in these examples, appears to differ from the process described by Washburn and Severance (see preceding footnote). The meaning supplement in the case of words does not involve a change in the *form* of the sensory data, as it does, in a sense, in the perception of the objective size-identity of two objects whose images are unequal in size, or in the perception of the circular form of an object whose image is elliptical.

all words are devoid of meaning for us; they are stimuli to mere sensations, as the words of Chinese or Russian are for most of us as adults. Again, the same word may have a number of meanings, depending on the context in which it is used. In printed or written form a small change in spelling, e.g., the difference between "rein" and "reign," acts as the "sign" in arousing a difference in percept, but in the spoken form this cue is absent and only context serves to guide us in the proper perceptual directions. Synonymous words, on the other hand, or words chosen from several languages, may have identical meanings along with widely different sounds (e.g., man, homme, Mensch). The fact that the sensory and memorial, or sign and meaning, reactions may be thus varied independently of each other is a simple testimonial of their basic functional independence. The facts of mind blindness mentioned earlier in the text offer another evidence of the double constitution of the perceptual process. Here some one or more of the forms of mental supplementation is deleted from visual experience.

The discussion should by this time have thrown some light on the mechanism involved in the visual percepts whose description introduced this section of study. The visual impression which would be expected to result from the character of retinal stimulation, and visual experience as we actually know it, it was seen, may be two quite different things. Distance, position and illumination may unite to distort the sensory image out of congruity with the mental impression, or, in other words, to bring about a marked difference between the sensory and the perceptual impressions of objects in the physical world. It is the memory supplement, it will now be seen, that corrects this lack of correspondence and ensures a stable and fairly constant relationship between the perceptual impression and the object perceived. The characteristics of bare visual sensation may not check with the properties of the "thing as it is" (in the sense explained earlier) but the percept, which combines past experience with the sensory image, can be depended upon to do this most of the time.

Thus, an object is perceived to be constant in size as it approaches despite the growth in size of its ocular image because we have learned to interpret this growth as a *sign* of diminish-

ing distance, rather than as a change in the physical dimensions of the object itself. Experience has taught us, partly through the sense of touch, that the sizes of objects, with few exceptions, are stable properties, and it is this basic item of knowledge which enters as an elementary part of all our percepts. Visual changes in dimension are therefore associated with (i.e., come to mean) different distances, instead of different sizes, because of our discovery that it is the former that vary rather than the latter. We see the thing, then, not as it distortedly appears to us but as we perceptually know it to be.

Similarly we learn through occasional visual and "handling" experiences that the "real" table is a flat, circular surface, and it is as such that we habitually perceive it, though customarily it may appear to be quite different, e.g., as a flattened ellipse. All of its various appearances, as it is viewed from various angles, are merely so many *signs* by which we perceive the "real" table (which is the *meaning* of the sign), in the same way that a half-dozen variously sounding synonyms may have the same significance.

In the case of motion, again, experience teaches that a body's apparent rate of movement (corresponding to the rate of stimulus movement across the retina) is not a reliable sign of the "real" rate until it has been corrected for distance. We observe, from train windows, for example, that the nearer the objects seen, the more rapid their passage across the field of vision, and that the rate of this passage is roughly proportional to their distance. Automatically we allow for the distance factor in judging rate, just as we allow for it in judging the size of a man, or for the angle of view in judging shape. Movement-in-the-distance, as a visual sign, we learn to perceive differently, in respect to rate, from movement-close-up. The former may mean great speed, however slow as a sensory experience, just as great size, with sufficient distance, is not incompatible with a small sensory image. The significance of these cues (signs) is aroused in our perceptual consciousness as immediately as an overcast sky imports rain, and in the same manner. The "experience formula" may be readily applied to other instances listed in the foregoing pages.

## THE PHYSIOLOGY OF PERCEPTION

We may now leave the consideration of visual experience itself for a few moments and turn briefly to its theoretical physiology. What physical events in the nervous system are the foundation for that conscious event called a percept? The latter was described as a type of associated reaction in which sensory and memorial components are combined, a fact which immediately suggests the phenomenon of "conditioning" discussed earlier in the text. The reactions involved in the experiments on conditioning were of the forms known as motor, emotional, and glandular. But mental events are also reactions —merely being aware of a thing is to be considered as a reaction to it—and it would be surprising if the principle of association or conditioning could not be applied as well to this extremely vital field of behavior.

A simple case may be taken in the synthesis of a percept combining visual and kinesthetic impressions. A piece of aluminum is held in the hand and scrutinized. Two sensations result: one expressing the arousal of activity in the visual cortex, the other a simultaneous activity in the cortical areas whose functioning generates sensations of muscle effort. A flow of impulses occurs between these centers in both directions, leaving behind a structural modification in the connecting pathways which facilitates future inter-drainage. At a later time the metal is seen but not held. The observer is now conscious of two facts: its visual appearance and its lightness, though the latter content of consciousness is not at the time a result of sensory stimulation. The lightness is remembered. Activity has been set up in the visual centers by impulses flowing in from the retina. Some of these impulses pass over into the kinesthetic centers and rearouse activity there which is experienced as a memory of the previous muscle sensations.[102, 103, 104] Assumedly this rearousal must be less energetic than the original arousal, since the memory of the lightness impression is much less vivid than the sensation of lightness. Neural activities set up by impulses flowing in from other centers must lack the vigor of those receiving their flow from the sensory surface. Again, the original sensory impression,—or rather the neural process underlying it, must leave a structural modification somehow corresponding to the nature,

pattern and quality of that impression, so that the subsequent reactivation of these structures results in a reproduction of the original, although, as stated before, in a weaker form. Such modifications have been compared, crudely, to the grooving of phonograph discs for the reproduction of air-waves which are finally translated into music.

Inasmuch as either of the sensory stimuli may incite a perceptual reaction, i.e., since a recurrence of the tactual and kinesthetic impressions in the above instance may lead to arousal of the visual image of the metallic object, we must assume that the interconnecting paths are established in both directions between the cortical patterns involved. In this regard it will be recalled that a vast number of association fibres connect the various cortical sensory centers with one another, providing the structural basis of "meaning," in these cases.

The distinguishing feature of recall in perception was stated to be its facility, rapidity, and the completeness of fusion of sensation with memory associates. Neurally this would mean that the repetition of the flow of impulses from the sensory centers to those basic to memory-consciousness must establish so permeable a connection—so low a "synaptic resistance," let us say—as to bring about a complete functional coalescence of the two patterns so that they act as a unit. Only the utmost speed, fluidity and integration of the underlying neural process would account for the characteristic qualities of the perceptual reaction

## INTERACTIVE PROCESSES IN PERCEPTION

The main effort of this chapter thus far has been to indicate the contributions of memory to visual impressions,—how past experience supplements and corrects present retinally supplied data. Where the impressions do not check with receptor stimulation it is found that the memory "overlay" accounts for the difference. It now remains to inquire whether *all* visual experiences can be regarded as so simply explained:—either as direct results of stimulation, like color, outline, brightness, etc., or as percepts. A number of facts are advanced as indicating that this is far from the whole story.

The case of "apparent motion" is one of them, and may serve as a simple introduction to a field of very interesting phenomena.

Some years ago a psychologist named Wertheimer was engaged in a study of visual movement. The substance of his discovery may be simply described. Imagine two luminous vertical lines, a short distance apart, projected upon a screen one after the other. The interval between the projections was then systematically varied. When the interval between exposures was as small as .03″ the two lines were seen simultaneously; they appeared to stand still side by side. With an interval of .2″ the observer reported seeing first one line, then the other; that is, he saw what was actually before him. But with an interval of .06″ or 1/15 of a second he reported that he saw, not two lines but *one* line which moved a short distance horizontally. If first a horizontal and then a vertical line were projected, instead of two verticals, the observer reported that the horizontal was seen to rotate through a 90° angle. By projecting four horizontal lines, with the proper intervals, motion was seen simultaneously in opposite directions.

Here we have one more case of a lack of correspondence between retinal stimulation and visual experience, but in this case the "experience theory," according to Wertheimer and the "Gestalt" psychology which he founded, is not adequate to explain the facts. The apparent motion is to be regarded as a sensory rather than a perceptual phenomenon; it is a peculiar expression of the "dynamics" of brain activity itself, under certain conditions of stimulation. There must be more than the mere arousal of two separate points of activity in the visual cortex, corresponding to the two stimuli; cross-currents of neural excitement must arise which somehow generate the experience of movement. Brain activity is not to be thought of as consisting of isolated foci. Complex interactions may take place between these points which add their own effects to experience.

This concept of cross-current processes in the visual cortex with their own peculiar expression in consciousness is further illustrated in certain studies of the reactions to facial expressions in pictures. One of these studies[105] made use of a large number of photographs of faces expressing various emotions, e.g., amusement, grief, irritation, etc. The prints were made in pairs and were cut horizontally into approximate halves, the eyes in one half, the mouth in the other, so that the halves could be inter-

changed and composite pictures made: the mouth of one person with the eyes of another, so far as the halves could be well fitted. The results, derived from the reports of a group of observers, showed, incidentally, that pleasant facial expressions are provided mainly by the patterns of the mouth muscles, but more importantly, that a pleasant expression of the eyes when combined with a mouth also expressing pleasure, changed immediately into an *unpleasant* one when combined with an unpleasant mouth. Similar investigations confirm this point. The expression of a local feature of the face may be made to change

*Fig. 17.* Observe the eyes with the rest of the face covered; then notice the change in the apparent direction of the gaze when the remaining features are exposed and the eyes are seen as part of a larger visual context. (From Luckiesh, Visual Illusions and Their Applications, D. Van Nostrand Co.)

when some other feature is changed, with no objective change in the original part (Fig. 17). Studies with silhouettes showed that the whole character of a face might be altered following relatively slight changes in individual profile features.

Still other and perhaps more familiar facts support the doctrine that a visual experience resulting from stimulation of a certain portion of the retina may be definitely modified by the action of stimuli upon adjacent portions. A piece of grey paper on a white background appears markedly darker than when seen on a black background. If a strip of grey paper uniform in shade is placed across a surface half of which is white and half black, the two halves of the horizontal zone of the retina affected by the grey strip will be stimulated with equal inten-

sity, but the appearance of the grey will vary depending on its surroundings. If a piece of yellow paper is placed on a sheet of grey, and both are covered by a thin tissue, a fringe of blue will appear at the boundaries. The color is experienced, thus, in the absence of its normal physical stimulus. Either the retinal processes which generate the experience of blue are set going by the presence of the adjacent processes basic to yellow, or, perhaps, the phenomenon is essentially cerebral in origin. In any case the facts demonstrate that visual impressions are not the result solely of *isolated* receptor or cerebral processes.

The traditional view of the general physiology of vision has been that the process begins with a multitude of independent points of retinal stimulation. In the instance of looking at a portrait, for example, the visual form of the face is simply a patterned sum of the separate features. Each item of the features sets up activity in a corresponding area of the retina, from which a whole constellation of impulses travels away to the visual cortex where each independent point of activity renders its contribution to consciousness, the separate bits making up the total impression of the face. This has been called the "mosaic" conception. The visual whole is a sum of independent and unitary parts.

Strong tendencies now exist to depart from this point of view. There are organizing processes in the visual nervous system, it is believed, which contribute very potently to determine the form of optical experience. These processes are essentially different from the relatively simple ones of associative memory previously discussed. A "dynamic interaction" must occur amongst the activities of the visual cortex, which generates many of the distinctive qualities of vision. These qualities, such, for example, as the facial expressions above referred to, cannot be accounted for by considering the visual impression as a kind of mechanical combination of independent pieces, because the characteristic appearance of a part depends on its relation to other parts, and may change if it is taken out of this relationship. Likewise visual impressions as *wholes* have certain qualities whose very existence derives from the mutual influences of the various parts taken together. Such wholes, which exhibit visual properties which cannot be specifically traced to any particular part, are called "gestalts." The solar

system, it has been suggested, is an example of a *physical* "gestalt," since the motion of every body in it is partially determined by the gravitational influence of every other body.

It may be said, then, that some of the features of visual consciousness are the result of the overlaying of memory material upon sensory data by the associative mechanism, while other features are the result of certain neural processes which take place at the sensory stage, before the work of association begins, or possibly concurrently with it, to some degree.

## PERCEPTUAL ORGANIZATION

One of the elementary properties of optical impressions which results from these fundamental sensory "organization" processes is known as the "figure-ground" relationship. Observa-

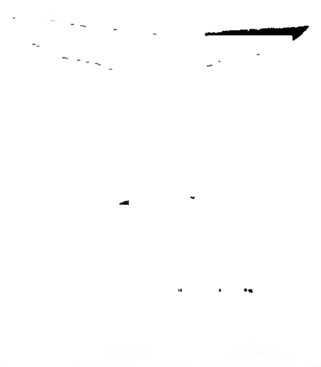

*Fig. 18.* Illustration of the relationship between figure and ground. (From Rubin, Visuell Wahrgenommene Figuren.)

tion of Figure 18 will disclose several facts. First, that there are two ways of reacting to the figure: at one moment two profiles are seen standing out as definite forms with the white space merely a formless "ground" behind the figure. The next moment a vase emerges as the main figure, while what was previously a black form with a definite character has now become a formless expanse of "stuff,"—simply the frame of the picture. The figure has compactness and unity; it is a "thing," while the ground is totally lacking in individuality and "thingness." Further, the two reactions alternate as wholes whose

parts are held together as coherent units. It is an either-or affair; the impressions do not blend.

The recognition of human faces in one case and of a familiar receptacle—or perhaps of a gas-burner with a spreading flame—in the other, is of course to be explained in terms of the past experience formula. But the fundamental figure-ground quality, seen in purer form in Figure 19, is held by the Gestalt school to be a deeply-rooted and inherent feature of the visual

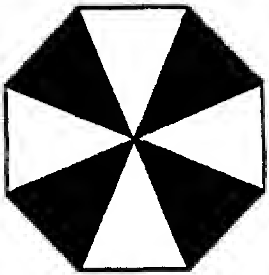

*Fig. 19.* Figure and ground. (From Bills, General Experimental Psychology, Longmans, Green & Co.)

function, and not a fruit of the learning process. We *always* see things in this way, they believe, as compact masses set off from relatively formless grounds, and this optical property is an expression of the inner dynamics of brain functioning. It is a *sensory* fact.

According to the older view, the infant first opens its eyes upon a world not only without meaning but without any separated *things* in it to serve as the centers to which meanings are to be bound up. It is a totally unorganized visual chaos, one great coalescing mass of color and line, the impressions of physically separate objects blending together. The infant must gradually learn in various ways that the world is composed of units, of separate things or wholes, before he comes to see it as such and before he can associate acquired meanings with these units. Only through experience do the visual forms of individual objects emerge from this primitive formlessness, as figures emerge and take shape out of a mist.

But the Gestalt writers believe that the figure-ground characteristic of vision is part of our native sensory equipment. People who acquire vision relatively late in life are unable, it is

true, to recognize objects visually which are familiar and meaningful to them as touch experiences, but it is significant that they understand the question when a "certain something" is referred to. It may be inferred that they are at least aware of their visual impressions as units, however empty otherwise the impressions may be.

**Factors in Organization.** As to the conditions under which visual stimuli are perceived as unitary, as wholes or coherent groups, a few simple factors may be mentioned. One of them

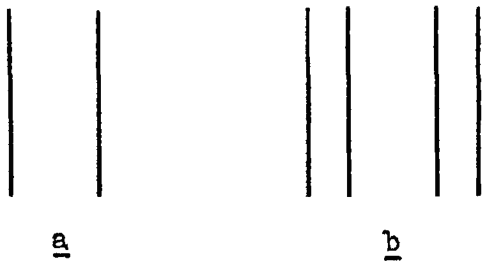


*Fig. 20.* Proximity.

is *nearness.* In Figure 20 (a), for example, the two parallels may be perceived as a unit, the space between having an enclosed or "interior" quality, the figure as a whole being set off from the surrounding space. If now two more parallels are drawn on the outside of the first two, as in Figure 20 (b), the first unit is disintegrated and two others are formed, the space which was previously seen as part of a "figure" now being changed to ground, to "mere nothing."[100]

It requires considerable effort, in Figure 21, to separate the pairs composed of dots that are close together and to visually

*Fig. 21.* Proximity.

grasp instead the pairs composed of adjacent dots that are farther apart. The influence of nearness as a grouping factor is clearly seen.

Another factor is *similarity.* In Figure 22 it is much easier to see rows of similar than rows of dissimilar elements. The

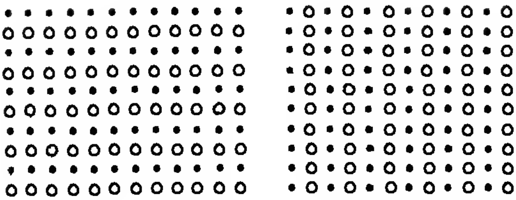

*Fig.* 22. Similarity. (From Woodworth's Psychology, Henry Holt & Co.)

principle of "closure" may overcome the influence of nearness, as in Figure 23. The vertical pairs with inward-pointing hori-

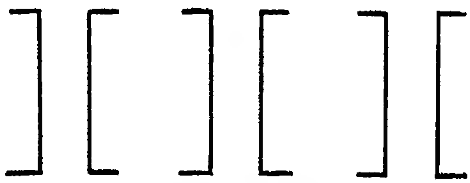

*Fig.* 23. Closure.

zontals tend to group themselves despite the fact that the pairs with outward-pointing horizontals are much closer together.

*Inclusiveness* has been considered as another factor. Two triangles are discernible in Figure 24, but the star figure is more readily and naturally seen, not because more familiar but

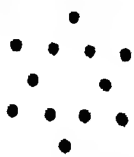

*Fig.* 24. Inclusiveness. (From Woodworth's Psychology, Henry Holt & Co.)

because it includes more of the stimuli. The Gestalt school has further emphasized that however familiar a figure, its perceptibility may be reduced to zero if it be "imbedded" in a new and different context. In Figure 25, (a) is contained in (b) but is not perceptible, its stimulus capacity having been completely altered by its submergence in a new figure.

Some of these principles also apply, it has been pointed out, to the field of hearing. A melody may be transposed into a

different key, yet instantly be recognized as the same, though all the constituent notes differ from the original; the melody has a form-quality of its own. The figure-ground distinction

Fig. 25. Submergence.

is apparent in the relationship between melody and accompaniment, the latter serving merely as a frame or context for the former. Again, notes following upon each other closely in time tend to be grasped as units in the same manner as points closely adjacent in space.

There are other more familiar phenomena of psychological optics which may be mentioned here, since they appear to depend partly upon certain factors of brain dynamics. The frequent shifting which takes place during the observation of figures having "reversible perspective" appears to be of this

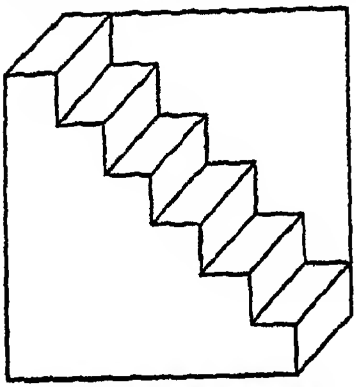

Fig. 26. Alternating percepts.

character. Figures 26 and 27 illustrate this. Changes will be noticed if the figures are studied. Beyond question experience enters into the *content* of the percepts in these cases; no one will recognize a staircase in Figure 26 who has never seen one

previously. Various forms may be deliberately constructed to operate as adequate stimuli for more than one perceptual reaction.* The occurrence of automatic reversals of perspective, however, may be attributed to cortical factors at present not

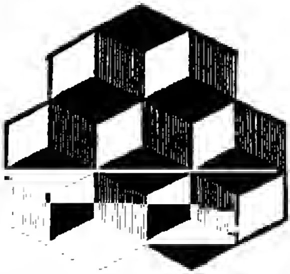

*Fig. 27.* Alternating percepts.

well understood. Similar phenomena have been observed in what is termed retinal rivalry. When a pattern of horizontal lines is projected upon the left eye, and a pattern of verticals on the right, as can easily be done with a stereoscope, a comparable shifting impression results. The horizontals alone are seen one moment; the verticals alone the next, or perhaps a patchwork effect in which the two alternate in prominence. A barely visible spot on a sheet of white paper will disappear and reappear rhythmically if gazed at steadily.

. . . . . . .

The earlier sections of this discussion should have made clear in some measure the statement that "we perceive things, not as they are, but as we are." That is, we perceive them not in the momentary guise with which our receptors present them, but clothed with and often transformed by the memory "over-

*The reactions to such figures have at times been referred to as "illusions of reversible perspective." This designation seems improper. The figures supply an adequate visual stimulus for two different percepts in somewhat the same sense that a word may have two meanings. Neither percept, however, contains an illusory impression; in neither case is there distortion, or any suggestion of "seeing something that is not there." When six cubes are perceived in Figure 27, for example, there are six spaces which comprise the "ground." When seven cubes are perceived, three of the latter spaces withdraw from the ground to constitute the seventh cube. The perceptual impression in either case is "true" in that there *are* as many represented cubes as one sees. At least there is no more illusion here than in the perception of depth in any two dimensional representation of a three dimensional object.

lay" which long and various experience with them has provided. We perceive them not merely as they *look*, but, more important, as we know them to be. "More important" because the knowledge fused and crystallized in our percepts is vitally related to the very practical matter of handling and using the things we perceive in a manner suited to their natures and to our purposes with them. Visual impressions, it has often been observed, are more richly freighted with meanings than are the data of any other sense. In the case of no other sense is the pure sensory data—the impression supplied by the receptor—so "degraded" to the status of a mere *sign*. The substantial content of the visual percept, then, is the object, not as it appears at the moment but as it has been consistently reported previously through the channels of every sense which it can affect.

Comment has often been made on the difficulty of teaching children and even fairly mature art students to depict objects in the color, brightness and figural distortions which illumination, distance and position have given them at the time of drawing or painting them. There is a strong tendency, expressing the perceptual habits of long experience, to overlook the sheer sensations of color, line, and luminosity, and to represent objects in their conventional or "standard" appearance. The novice must be instructed to draw objects as foreshortened—their farther parts reduced in size—in spite of the fact that his retina nearly always supplies him with foreshortened images. The child will sketch rectangular objects as rectangular, circles as circles, failing to note that they are non-rectangular and elliptical, respectively, if he will pause to separate his knowledge about them from the raw sensory effects. Similarly he may draw distant objects the same size as nearer ones; the sides of a receding street as equidistant. He must be taught to gauge the "picture size" of objects by holding his brush or pencil vertically toward them so as to intercept their image, mark off the height and carry it to his paper.

The difficulty in relation to color was suggested in an example previously given of an illusory hue impression. Many of these have been reported.[107] To see object-colors as they "really are" we must make allowances for the deceptive possibilities of momentary illumination. If, for example, an object appears blue under white light, we perceive it as blue; if under blue

light it seems of the same blueness as the illumination we perceive it as white; if under the same conditions its blueness is richer than that of its illumination we perceive it as itself blue.[108] The artist, however, must train himself to set aside such sophistication and represent the colors of objects as illumination makes them. If green trees are blue in the distance, or grass greyish yellow under the setting sun, he must paint only the impression he gets.

It has been observed that the colors of a landscape "come out" more brilliantly when viewed with the head held horizontally or upside-down. The scene then tends to be perceived more as a flat surface; colors cease to be mere partial signs of objects and are seen in their full sensory richness. The memory overlay is removed, to a degree, leaving the sensation; the effects being similar to those following the repetition of a word. The more familiar we become with sensations solely as signs, the less are we conscious of their intrinsic sense qualities.

In some cases it may be very difficult to effect this divorce between visual sensation and meaning. It was stated earlier that if two cardboards of unequal size be placed at such distances as to cast identical images on the retina, they will nevertheless be perceived in their true dimensions, and it is almost impossible to perceive them otherwise. Only under rather elaborate conditions, such as viewing them through openings in a screen in a darkened room, and during very short exposures could they be seen as of equal size, i.e., seen in harmony with retinal stimulation. Such special arrangements would be necessary in order to exclude the operation of those signs which enable us to perceive the difference in distance and therefore to "allow" for this in judging size. The point will be clearer after the following chapter has been studied. It may be added, in this connection, that it has been said to be possible to cause an approaching human figure to appear to grow in size "by setting our attention in a peculiar way."

Finally a word may be said as to the function of visual perception in every-day behavior. Of what value is it to the individual to have memories associated with sense impressions? It is very difficult to glimpse the realities of a state in which one would be unable to identify the nature, characteristics and uses of the most common objects; to recognize friends; to read;—un-

able even to be conscious, as will be seen later, of the distances and the third dimensional character of the things about us. Mind blindness may be a not much less serious disability than complete loss of vision. In percepts are summarized and concentrated the most immediate, practical and elementary items of knowledge needed for dealing effectively with the environment.

The function of percepts in behavior is in fact so thoroughly unconscious and taken for granted that only if they ceased to operate could we fully realize their value. We see the darkened sky, perceive it as signifying rain and decide to stay in the house; we see a darkened patch on the sidewalk, perceive it as water and avoid wetting our feet; we see the agitated surface of the water on the stove, perceive it to be at high heat and ready for its purpose; see a twitch in the features of an auditor, perceive him to be irritated and modify the conversation accordingly; see the image of an automobile expanding rapidly, perceive it as approaching at high speed and give it plenty of room;—the list is literally endless in the field of vision alone. A very large part of the general process of "profiting by experience" might be described in terms of perceptual reactions; they are the means whereby what we learn is fixed, preserved and made a permanent part of our equipment for the details of concrete adjustments. Every percept is an archive of the past and an instrument for dealing more skilfully and less wastefully with present and future encounters.

## Chapter V

# VISUAL PERCEPTION OF SPACE

The term "space perception" is a conventional one in psychology. It refers primarily to our consciousness of the spatial relationships between objects, and of their space-filling characteristics. The present chapter is intended as an elementary introduction to the analysis of our visual consciousness of such things as the size, shape and motion of objects, and their location with reference to each other and to the observer.

Some of the outstanding problems of vision come to light when we attempt to discover how much of visual experience can be plausibly accounted for by the manner of receptor stimulation. The general point was discussed in the preceding chapter, where many instances were discovered in which such an explanation was lacking. Some further cases of the same kind and of a more fundamental character will now be dealt with.

As was noted earlier, our visual impressions of such features of objects as their color and brightness are to be attributed to such factors as the wave length and the energy of the physical stimulus. The shape of the ocular image corresponds to the two dimensional shape, at least, of the object, while, at the same distance, large and small objects will provide, respectively, large and small images. As an object moves from left to right in the field there is a corresponding change from right to left in the location of its retinal image. It is unnecessary to go further into detail to indicate that these elements of experience are sensory in character.

On the other hand the *distance* of the "object of regard" does not appear to fit into this formula, a fact which has been recognized as far back as the seventeenth century. The nature

of the difficulty may be introduced with the much quoted statement of Berkeley "—that distance, of itself and immediately, cannot be seen. For, distance being a line directed endwise to the eye, it projects only one point in the fund of the eye, which point remains invariably the same, whether the distance be longer or shorter."[100] The observation was made considerably earlier than Berkeley though it is perhaps with his name that it is most frequently associated. Restating it, we may say that the distance of an object cannot be truly visible because the eye cannot tell, so to speak, from how distant a point of origin a ray of light has traveled. If such a ray be concretely imagined as a straight line, the retina can record its cross-sectional magnitude but has no means of gauging its length,—i.e., the remoteness of its source. Despite, therefore, the fact that the distance of objects is as clear and definite a feature of our visual impressions of them as their color and form, the eye would appear to be structurally incapable of providing it.

By the same logic the depth, or front to back dimension of objects, cannot be visually given. Height and width may register upon the two corresponding retinal dimensions, but there is no direct way by which the third dimension of objects could conceivably affect this two dimensional sensory surface. The artist, for example, can *represent* depth and distance on his paper, but his pencil strokes must necessarily be in a flat plane. By using certain simple perspective devices he is able to create the illusion of depth and distance, but in reality, of course, everything drawn is in the same plane. The retina may be considered as a similar recording-surface.

The problem, then, is to explain how, if the eye is incapable of furnishing us with depth and distance consciousness, we nevertheless are so immediately and emphatically aware of these facts. The clue to a possible solution should suggest itself from the earlier discussion of perception. A number of cases were described in which visual impressions included—or seemed to include—qualities of experience which were by nature non-visual. The mechanism of association is capable, it was seen, of so closely combining the memories of, e.g., tactual sensations, with the immediate results of retinal stimulation as to produce a composite effect in which both sensory qualities are blended.

The formula is, then: when an experience includes any element which cannot have been provided by the active receptor, we must turn to some other sensory channel the memory of whose impressions is the source of this element.

It remains to find a sense which can provide the direct and original experience of distance and depth,—a sense which is related to these facts as flavor is related to the taste sense and odors to the olefactory sense. It was long ago suggested that only the sensations which arise from muscular movement could satisfy the requirements. The way in which we directly *sense* the amount of space existing between ourselves and an object is to move our bodies through space to reach it, or to extend a hand forward to grasp it. The movement will furnish a given amount of the sensation of muscle effort, and to varying distances will correspond various amounts of this experience of effort. Thereafter the memory of such effort becomes associated with visual impressions in the same way that touch or temperature memories become bound and blended with images. "Distance from one seems primarily to be a motor affair. Things are 'farther away' in the sense, originally, that I must—take more steps, or consume more time in getting to them."[110] The statement "I see the distance," as Hollingworth says, symbolizes the same psychological process as does "The water looks cold."

Distance consciousness, according to this theory, is a perceptual reaction in which the meaning is kinesthetic. The crude space measures indicated in such phrases as "a day's journey," "at twenty paces," "at arm's reach," etc., suggest the primitive origin of the distance concept. The principle applies similarly to the case of object depth. We learn the front to back extension of things by a corresponding front to back extension of our hands about them. "Handling" experiences are basic to visual percepts of the third dimension of physical bodies, as well as of their solidity and their touch qualities. To explain the problem of visual space, then, "—all empiricists fall back on muscular activity and sensations derived from the contraction of the muscle and from the changes thus produced in various parts of the body. They maintain that if all muscular activity and the memory of such activity were banished, stimulation of the mosaic of retinal visual elements could never become associated

with the idea of space."[111] Helmholtz believed that the idea of space itself must be developed by experience; others have held that only the localization of objects within an original spatial frame must be learned.

Though not conclusive, some evidence for this view emerges from cases of late acquisition of vision following operation for the removal of congenital cataract.[112, 113] The evidence is imperfect on one count in that rarely have the observers of such cases been much concerned with the issue of primitive vision. The opacity of the lens, moreover, is incomplete; the majority of these patients can discriminate brightness differences; some are able to locate luminous objects. In general, however, it is reported that, following the removal of the cataract, accurate appreciation of distance, as manifested in the ability to grasp objects seen, is absent. In three instances visual objects were reported as in contact with the eyes, often as located close to the face. Things familiar to touch cannot be recognized or identified visually. The guidance of movement under visual control is very defective, although there is visual awareness of objects as located above, below, to the right, left, etc.; likewise of form and color. It appears permissible to draw the conclusion that visual consciousness of depth and distance in these individuals is subnormal.*

*Description of a case is quotsd by O. O. Norris (The Nature of Distance Vision, Jour. Exper. Psychol. 1934, 17, 462-476) from Frassr's edition of Berkeley's Works (3 vols.) Vol. I, Pp. 446-448. The patient, a boy, had been congenitally blind from cataract. He was able to distinguish day from night, and one color from another, but was unable to make out the shapes of objects or their distance from him. He had learned to distinguish a cube from a sphere by touch before the operation for removal of the cataracts. "After keeping him in a dark room for a few days (sic),—the same objects, which had been kept carefully from him were again presented to his notice. He could at once perceive a difference in their shapes; though he could not in the least say which was the cube and which the sphere, he saw they were not of the same figure. It was not until they had many times been placed in his hands that he learnt to distinguish by the eye the one which he had just had in his hands, from the one placed beside it. He gradually became more correct in his perception, but it was only after several days that he could or would tell by the eyes alone, which was the sphere and which the cube.—Of distance he had not the least conception. He said everything touched his eyes, and walked most carefully about, with his hands held out before him, to prevent things hurting his eyes by touching them. Great care was required to prevent him from falling over objects, or walking against them. Improvement gradually went on, and his subsequent sight was, and now is, comparatively perfect."

Investigations conducted with lower animals sometimes give evidence tending in the opposite direction. Some recent experiments, for example, have demonstrated innate visual distance perception in the rat. Lashley and Russell [111] reared a group of rats in darkness until the animals were one hundred days of age. All visual experience was thereby excluded. The experiment consisted of placing the hungry animal on a platform from which he must leap to a second platform to reach food. The jumping-platform was fitted with a device by which the force of the animal's leap could be recorded in grams of foot pressure, the logic of the experiment being that if this force varied with the varying distance of the landing-platform it would indicate an initial visual distance judgment on the part of the animal, expressed in the vigor of his effort. In a preliminary practice period the rats made the first attempt of their lives to jump to a visual object, placed 20 cm. away. All exerted a force in excess of that required, but this force was steadily reduced during ten trials. In the first attempt with the landing-platform 40 cm. away, all but three of the thirteen leaped with much greater force than in the last jump at 20 cm. The average force for the last five trials at 20 cm. was 6.8 grams; for the first jump at 40 c., 15.4 grams. Few of the jumps were successful in reaching the landing on the first attempt, but the significant fact is the immediate increase in the vigor of the jumps for the greater distance. In a following series of tests for visual discrimination of new distances the animals made a score very nearly as good as that of a control group reared under normal daylight conditions. This was after a practice period consisting of but thirteen attempts at 20 cm. and six at 40 cm. The force varied for changes in distance of less than 2 cm.

An inborn visual distance sense for objects within 40 cm. is demonstrated here, though of course no deduction can be made in regard to human vision. The work is significant, however, in showing that visual space judgments are possible on a basis of innate organization. Both the experience theory and "nativism" have been represented by outstanding authorities in psychological and physiological optics. While the question as to whether visual space consciousness is natively given or develops with

experience has not been answered on the basis of existing evidence, there is general agreement that learning is needed before the spatial *localization* of objects,—i.e., accurate judgments of distance, is possible. We therefore turn to the more important discussion of the factors involved in such judgments.

## MONOCULAR VISUAL FACTORS

First to be considered are the so called "monocular signs" of distance. Under this heading are included those characteristics of the visual impressions of objects which vary with their distance and which are alike for both eyes. That is, these signs may be adequately described without reference to the fact that human vision is binocular. A one-eyed person, so far as his distance estimates are concerned, is as well off, in respect to these factors, as a person with normal vision.

**Size of the Image.** This is usually given first place in the list, and will be dealt with somewhat at length, since the principle involved in its operation as a distance sign applies to a number of others. The retinal images of objects swell and shrink as the objects approach and recede from the observer. Moreover a small image may be cast by a small object close by or by a large object in the distance. Similarly a large image may be cast by a small object, if close enough, or by a distant object, if very large. How then can the size of the image be a dependable sign of the distance of the object? The answer is clearly stated by James: "Out of all the visual magnitudes of each known object we have selected one as the REAL one to think of, and degraded all the others to serve as its signs. This 'real' magnitude is determined by esthetic and practical interests. It is that which we get when the object is at the distance most propitious for exact visual discrimination of its details. This is the distance at which we hold anything we are examining. Farther than this we see it too small, nearer too large.[115]

In other words we must know the "real" size of an object before its various "apparent" sizes can function as signs of distance, and this "real" size is its close-up size,—its "visual spread" when it is within range of manipulation or of comfortable scrutiny (Fig. 28). Its various sizes at different distances

then become its "apparent" sizes, smaller in visual spread. But the size of an object as a touch experience does not vary as it does for vision. The visual size at "handling distance" is more "real" only because of this associated constancy of the visual and tactual experiences of size and because, perhaps,

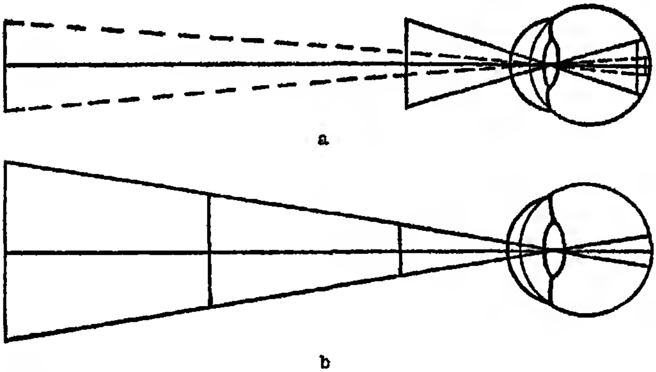


*Fig. 28.* (a) If "real" or tactile-motor size is known, apparent size or "visual spread" functions as a distance sign, since it increases and diminishes as the object approaches and recedes. (b) If "real" size is unknown, apparent size cannot operate as a distance sign, since objects of different physical magnitudes at different distances, give images of the same size. (From H. L. Hollingworth, Psychology: Its Facts and Principles, D. Appleton-Century Co.)

the impression of reality inheres more in the sense of touch. It is when we can get things in our hands that we feel that we know them as they really are. The distinction between real and apparent is therefore, in this sense, an arbitrary one. All retinal images are equally real.

The efficacy of size as a factor in distance perception is well established, the relationship between the two being an inverse one. By varying the size of the retinal image of an object it is possible to produce corresponding variations in perceived distance without altering the actual distance of the object, i.e., illusions may be produced. One demonstration of this type[110] involves two illuminated boxes containing round windows in front, the size of which can be varied by diaphragms. (Figure 29). In the dark room the observer sees only the luminous windows. The boxes can be moved on tracks, nearer or farther from the observer; size and distance are the only factors present. Under these conditions if the windows are made

unequal in size but located at the same distance, the observer will see the larger as the nearer. If the smaller window is then brought closer until seen as at the same distance as the larger,

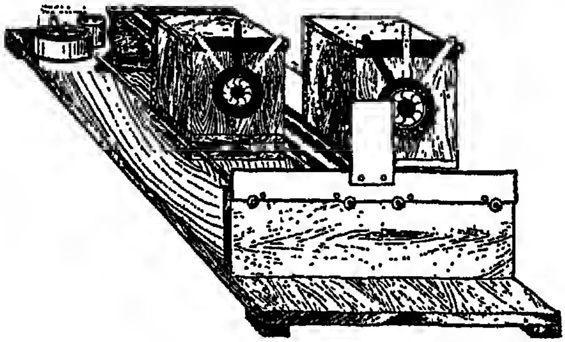

*Fig. 29.* Apparatus for studying the relation between distance judgments and the size of the visual image. (From Bills, General Experimental Psychology, Longmans, Green & Co.)

the relationship between size and perceived distance may be quantitatively obtained, i.e. the amount of distance which a given increase in size of image "stands for."

A good summary is provided by Helmholtz: "The same object seen at different distances will be depicted on the retina by images of different sizes and will subtend different visual angles. The farther it is away, the less its apparent size will be. Thus, just as astronomers can compute the variations of the distances of the sun and moon from the changes in the apparent sizes of these bodies, so, knowing the size of an object, a human being, for instance, we can estimate the distance from us by means of the visual angle subtended or, what amounts to the same thing, by means of the size of the image on the retina. Persons or domestic animals in a landscape are particularly good objects for this purpose, because they are easy to recognize by their movements, they do not vary much in size, and we are familiar with them. Soldiers, especially, are usually trained in this way to gauge correctly the distances of remote bodies of troops in an unfamiliar country. For military purposes also various little optical devices have been designed for measuring the apparent height of a distant man and then reading the corre-

sponding distance on a scale attached to the instrument. Houses, trees, plants, etc., may be used for the same purpose, but they are less satisfactory; because, not being so regular in size, such objects are sometimes responsible for bad mistakes. A person accustomed to a flat country may easily take a vineyard or a potato-patch or pine trees on distant high mountains for heather, and thus underestimate both the distance and the height of the mountains.[117]"

The artist makes use of size not only in giving the appropriate relative distances to the objects represented but in shaping the outlines of the objects themselves; the more distant parts of houses, roads, etc., must be drawn smaller than the nearer parts. The telescope, by magnifying the image, gives a vivid illusion of nearness to things seen by its means. Various illusions based upon the intimate relationship between size and distance will be described in a later chapter.

**Brightness.** This is another factor in distance perception. The intensity of retinal stimulation varies inversely as the square of the distance of the stimulating object,—an ocular application of the physical law relating to the brightness of illuminated surfaces. Since brightness and distance vary in a regular fashion, the one may be used as an index or sign of the other: the brighter the object under constant illumination, the closer it will be perceived. The principle is used in a simple way in painting. Distant objects are more darkly shaded; likewise the richness of their colors is diminished,—a decrease in "saturation." Under experimental conditions, with all factors under control, distance judgments can be shown to vary as brightness varies.

**Clearness and Detail.** With distance the outlines of objects tend to lose their definition and sharpness, and the visibility of detail is diminished. A great amount of dust and smoke, especially in cities, is suspended in the atmosphere, and the blurring effect of this material upon objects seen will naturally increase with distance. Moisture increases the effect. The artist paints near objects with well defined contours and conspicuous detail; far objects are outlined less distinctly and with omission of the more minute items. This loss of detail with distance is partly due to the visual threshold of discrimination; two points of an

object, or two objects, if close enough together, will be fused as one.

**Overlapping.** This is a sign of relative distance. If a portion of one object intercepts vision of part of another, the former is perceived as nearer (Figure 30). Obviously one


*Fig. 30.* Overlapping. (Reprinted by permission from "Psychology" by Boring, Langfeld and Weld, published by John Wiley & Sons, Inc.)

object must be closer to the observer than another if it is to cut off any of the light rays coming from it to him. Consequently when, in a painting, a tree excludes vision of part of a house, and the house does likewise for a hill, we at once perceive the spatial significance of these cues. Overlapping, unlike the rest of the criteria here listed, permits only relative distance judgments. A large amount of overlapping signifies no more than a small amount, and both indicate only that one object is closer than another. No clue is provided as to the distance of either or both from the observer. Thus one might feel very unsure of a judgment as to the distance of either of two vessels at sea, owing, among other things, to lack of knowledge of their sizes, yet instantly perceive one to be nearer than the other by reason of visual interception. A prerequisite to the use of this sign, of course, is a recognition of objects as separate units. Unless we are sufficiently familiar with them to be able to do so, overlapping, under certain circumstances, would supply no information as to relative distance. Conceivably an instance might arise in which a line representing the demarcation of two separate objects might be taken as an integral part of the visual pattern of a single object. It must be remembered, however, that the signs under discussion typically operate collectively, and that the absence of one of them in any given case will be compensated for by the presence of others on whose basis a judgment can be formed.

**Vertical location in the visual field.** The horizon line is typically represented in the image and forms a fairly stable point of reference in the visual field. A glance at any landscape will show that the more distant an object the closer will be its approach to the sky line and the higher its vertical position in the field. When the artist wishes to represent one object as more distant than another he will, among other devices, place its base higher on the canvas, as illustrated in

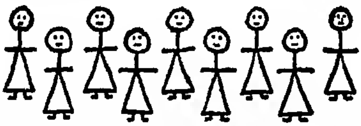

*Fig. 31.* Vertical position in the visual field as a sign of distance. (From Smith & Guthrie, General Psychology in Terms of Behavior, D. Appleton-Century Co.)

Figure 31. This apparent vertical or "up and down" distance between object and horizon or between one object and another is perceptually transformed into "here and there" or third dimensional distances. The formula may be stated in terms of the field of vision or of retinal stimulation. The sky line functions again in distance judgment when it begins to overlap the object which is "beyond the horizon." The upward movement toward the sky line, as a ship, for example, moves away, is followed by the downward movement which along with over-lapping signifies still greater distance. The sign, generally, affords a basis for judging the distance between object and observer as well as that between objects themselves. In its absence, as in the case of observation of an airplane, distance estimates are greatly lowered in accuracy.

**Relative motion.** It is a fact of common knowledge that in train travel the rate with which objects appear to move past the observer depends upon their distance. The ratio between apparent velocity and distance is here an inverse one: the greater the distance the slower the rate of movement. The same fact may be noticed, of course, in walking. Road-side objects move by rapidly; remote objects appear stationary. Visual factors which vary regularly with distance may function as signs of distance. Rate of apparent movement thus satisfies this requirement. To quote Helmholtz again: objects ". . .

that are farther off as compared with those that are nearer seem to be advancing with the observer, whereas those that are nearer seem to be coming toward him; and the result is we have a very distinct apperception of the fact that they are unequally far from us. Suppose, for instance, that a person is standing still in a thick woods, where it is impossible for him to distinguish, except vaguely and roughly, in the mass of foliage and branches all around him what belongs to one tree and what to another, or how far apart the separate trees are, etc. But the moment he begins to move forward, everything disentangles itself, and immediately he gets an apperception of the material contents of the woods and their relations to each other in space, just as if he were looking at a good stereoscopic view of it."[118] Helmholtz observes that it is the absence of this relative motion of parts which among other things distinguishes a scene of any kind from a picture of it. In the latter case the spatial relations between far and near objects do not change as the observer changes his position, and this fact tends to weaken the illusion of reality which the artist seeks to create.

Perception of object depth. The visual consciousness of the third dimension of objects was stated to be a perceptual reaction in which the meaning component is kinesthetic and tactual. The front to back extension of objects cannot register as such upon the visual sensory surface. What is the visual sign, then, of this optically unrecordable physical characteristic?

Under ordinary lighting conditions objects do not receive equal amounts of illumination from all directions. Some parts of the surface of a solid will not only be closer to the light source than others but will intercept light to the farther parts, thus placing these parts in shadow. Marked local differences in the amount of light reflected to the eye will result. To some degree such differences will also exist in the case of a flat surface, but will be much more marked if the object is three dimensional. Inequality of illumination—the factor of "light and shade," will then come, by association with handling experiences with solid objects, to be a sign of tridimensionality. Here again characteristic visual features are linked with the memory of impressions derived through another sensory channel. A much better perception of form is obtained from

drawings of objects if they are skilfully shaded than if they are represented only by outlines. Refined shading techniques have been developed in painting for the achievement of marked "volume" effects. For the same reason the forms in a landscape viewed in late afternoon with the sun near the horizon are more distinctly modelled into relief, owing to the distribution of shadows, than the same scene under the more uniform illumination of a bright noonday.

It is not asserted that in the absence of shading solid forms will be perceived as two dimensional. Obviously this is not true. A human figure would certainly be perceived as such even though absolutely uniform illumination could be arranged. The factor of shading merely strengthens the impression of depth. All objects may be said to have more or less characteristic two dimensional forms,—distinctive visual patterns and outlines. Once having learned by extended tactual and especially kinesthetic exploration the three dimensional form and magnitude of objects, we come to perceive them as possessing these characteristics once the typical and familiar two-dimensional pattern is presented to the eye. A man, a tree, a house, an automobile, in presenting its distinctive figure, immediately instigates the percept of its total dimensional character. Shading, when present, provides a supplementary sign of that character in the same manner in which overlapping might add its sign value to those of apparent size and clearness in evoking the percept of the relative distance of two objects.

A distinction may be made between the percepts of object depth and of solidity. The degree of the latter attribute may, of course, vary greatly, and all things with depth must have some degree of density. The term "solidity," however, suggests a rather high degree of resistance, and this is not necessarily true of all objects possessing a third dimension. We perceive a cloud, e.g. as tridimensional but hardly as solid.

## THE BINOCULAR FACTOR

The "monocular" signs, or as they are sometimes called, the "secondary criteria" of visual depth and distance, affect both eyes customarily but affect both in an identical fashion and may thus be called monocular in the sense that they may be considered in terms of visual experience as mediated by a single eye.

There are other monocular factors to be considered but since they are non-visual (kinesthetic) in nature their discussion will be postponed until that of the visual factors has been completed.

The binocular factor resembles the preceding in the fact that its basis is a condition which varies with the distance of objects; it differs from them in the fact that it functions only when both eyes are in use, and in the fact that it can hardly be considered with the preceding as a *conscious sign* of third dimensional relationships.

A moment's reflection will suffice to show that the two retinal images of an object held before the eyes must be unlike in pattern. The eyes being located some 65mm. apart horizontally, each must register its image from a slightly different point of view and therefore receive a different "picture" of the object. This can very easily be demonstrated by holding any solid object before the eyes, closing each eye alternately and observing the difference in appearance. A rough notion of the amount of this difference may be obtained by fixing with the right eye a pencil held so that only its end may be seen; then closing the right eye and noting with the left how much of the pencil can now be seen which was previously invisible. In any such case it must be true that each eye will see more of that portion of the object on its own side than will the opposite eye.

The difference in the visual appearance of an object as it is viewed with alternate eyes is the result of a corresponding difference in the horizontal pattern of retinal stimulation. Let the two forefingers be held before the eyes, the right a few inches more distant and about an inch displaced toward the right side of the body. Viewed with the two eyes alternately the horizontal distance between the fingers will be seen as greater with the right eye than with the left. This is an expression of the fact that the distance between the images on the right retina is greater than between those on the left. This type of difference in retinal stimulation is sometimes called "binocular disparity," and the difference in the position of the two eyes in relation to the object fixated is called "binocular parallax." Disparity, it will be seen, is a result of parallax. Now, when such horizontal pattern differences in retinal stimu-

lation exist, an experience results which is called the "stereoscopic effect" or "stereopsis,"—a name for the visual depth consciousness which is generated in this manner and which for purposes of study will be considered apart from that discussed earlier. The visual depth and distance consciousness which results from the operation of the previously listed signs will hereafter be referred to as the perceptual depth effect.

Unlike patterns of retinal stimulation occur only under certain conditions.[110] When the optic axes are parallel during the fixation of remote objects, such binocular differences do not exist. The retinal images are duplicates and the stereoscopic effect is absent. Under these circumstances the visual impression of third dimensional relationships is perceptual in character, that is, it is a sign-meaning affair. The same is true, even though the axes are convergent, when a flat surface at right angles to the line of vision is fixated, or in case of two or more objects equidistant from the eyes. This may be simply demonstrated by viewing a book or a card, so held, with alternating vision, and by doing likewise with the fingers. The visual pattern will be found to remain constant.

On the other hand, in case of two or more objects at different distances from the observer, or in case of a single three dimensional object, or of a two dimensional surface placed obliquely or at a slant with respect to the line of vision, the two retinal patterns will be unlike. The amount of retinal disparity, moreover, increases as the object or objects approach the observer, a fact which can be shown by viewing with alternate eyes any three dimensional object—one's fist, for example—at different distances, or by using a couple of pencils in the same way, if care be taken to keep the distance between them constant. It should be noted that two sets of relationships are involved here: first, certain dispositions of physical objects result in unlike patterns of retinal stimulation, while others do not; second, unlike patterns arouse the stereoscopic effect while duplicate patterns do not; moreover, the degree of stereoscopic effect increases with the degree of image difference. The one relation is physical-retinal, so to speak; the other is retinal-mental.

If these generalizations are correct, disparate retinal stimulation should produce stereopsis whatever the manner in which

the stimulation is supplied. If, for example, lines could be drawn on a flat surface in such a way as to cast images having the proper differences in pattern, a visual impression of depth should be aroused despite the absence of any actual depth in the object viewed. In such a case the experience would be called an "illusion" but would demonstrate the cause and effect relation between binocular disparity and stereopsis. The simple line drawings in Figure 32 represent pyramidal objects viewed from above and with the apices or tops removed. *B* represents

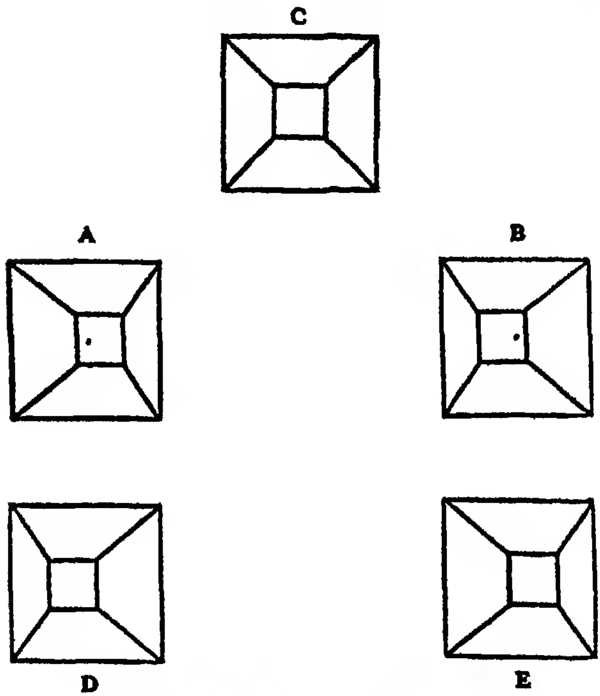


*Fig. 32.* Illustrating binocular image disparity.

the aspect which the right eye would obtain in viewing an actual object having such a form as C, while *A* presents the aspect which the left eye would receive. It will be noted that each figure (*A* and *B*) represents more of one side of the object than of the other. If the two are pasted on a card and viewed through a stereoscope *A* will fall on the left retina, *B* on the

right; fusion will take place with the proper adjustment, and a single pyramidal form will be seen exhibiting a marked depth effect. This is the highly realistic three dimensional impression familiar to everyone who has used an ordinary stereoscope. A certain amount of visual depth appears in such drawings when seen directly on the page, since the lines depict a more or less familiar object which *has* depth,—which we recognize and therefore perceive as such. The pronounced additional depth impression obtained with the stereoscope results, however, mostly* from the unlike images which such figures must obviously throw upon the retinas.

If the disparity is reversed, as in the lower pair of drawings in Figure 32, in which D and E are intended for the left and right eyes, respectively, the depth relations will likewise be reversed when the figures are fused stereoscopically. The small square will now be seen as more distant, instead of nearer, than the large square. The effect will suggest an impression of looking down a long corridor. In either case the stereoscopic effect can be increased by increasing the difference between the two patterns, i.e., by locating the small squares more eccentrically in relation to the large ones. If the small squares are perfectly centered and the resulting images thus duplicates, no stereopsis will result. The depth impression will be very little greater *with* the instrument than without it.

A word may be said as to the way in which the stereoscope operates. The diagrams or photographs, as the case may be, are placed in a holder at C, Figure 33. Two prisms, base out, are located at $x$ and $y$. Suppose the two diagrams of Figure 32 (A and B) be placed in the holder with the dots in the centers located at points L and R. The light beams from these points will be refracted outward by the prisms, and the eyes will converge to catch these beams on the fovea. Accommodation will adjust for the distance F. The light from the large squares will also fall on corresponding points. The smaller squares and the diagonal lines, however, will fall on non-correspond-

*A certain amount of depth effect, beyond that obtained by looking at the figures with the naked eye, is noticed when the stereoscope is used monocularly. It is never as great, however, as the binocular effect, and is the result, according to Carr,[140] of the influence of the prisms on the monocular signs. Only the binocular impression is true stereopsis.

ing points. Unlike patterns of retinal stimulation result but fusion will occur and a single figure is seen with its center at *F*; it will exhibit the characteristic stereoscopic depth impression. Since the retinas are being stimulated in the same way they

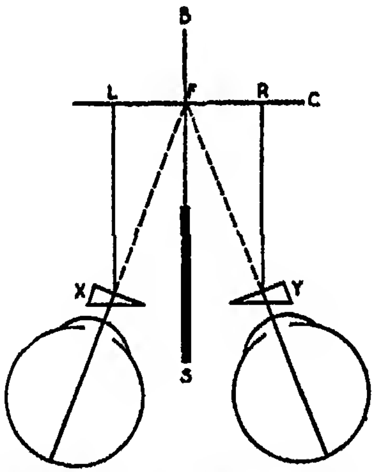


*Fig. 33.* Prism stereoscope. (From Carr, Introduction to Space Perception, Longmans, Green & Co.)

would be if a solid pyramid were viewed from above, the same impression of solidity is obtained.

From a geometrical viewpoint the small squares in Figure 32 cannot fall on corresponding points if the large squares do so. Similarly if the eyes adjust to place the small squares on corresponding points the large ones will not be so placed. Either one or the other would therefore have to appear double, theoretically. But in reality geometry is left behind here: the fusion mechanism creates coincidence for all parts of the figure and simultaneously it becomes tridimensional. It will be recalled that "corresponding points" are not to be considered as located with mathematically exact symmetry. If images fall on points which are very nearly but not exactly corresponding the object will be seen singly. A point on one retina corresponds to a small *area* on the other. If the images fall on points still further out of correspondence, fusion will still be preserved but the object now begins to exhibit extension in the

third dimension. It takes on depth. Finally, with still greater disparity the fusion power is pressed beyond its limits, the image breaks and the object is seen double. The stereoscopic effect seems therefore to represent an intermediate stage between single and double vision.

Those who are familiar with old-fashioned "household" stereoscopes know that two views, pasted on a card, are placed in a holder and brought into focus. If a depth impression identical to that which would be experienced by looking at an actual landscape is desired, the views must be taken from two points an interocular distance apart. The parallactic angle will then be equal to that of normal binocular vision. The two disparate images, cast on the retinas and fused, will supply a "natural" amount of stereopsis. The images of very remote objects will coincide in location on the two pictures. The images of nearer objects will be displaced towards the left in the picture taken by the camera on the right (and intended for the right eye); they will be displaced toward the right (relative to a remote point) in the picture taken for the left eye. The amount of such displacement will increase in proportion to the nearness of the objects represented. That is, as previously stated, the closer the objects the greater the disparity of retinal stimulation. All objects at a given distance will determine the same degree of disparity. Since the parallax approaches zero for the very remote points, no depth effect will be noticed in fixating upon them.

The degree of relief or depth which would result in the above-described instance would not be at all marked, especially for the more distant items of the picture. The interocular distance is not great enough to afford more than negligible disparity for remote objects. In order to create the striking depth effects achieved with the commercial stereoscope the photographs must be taken from stations a greater distance apart, the space interval depending on the remoteness of the scene desired. Otherwise, when seen stereoscopically the relief will flatten out toward the horizon.

The *telestereoscope* is a device especially constructed to exaggerate stereoscopic effects by increasing the pattern differences in retinal stimulation. In Figure 34, *m*, *F*, and *n* indicate

mirrors which reflect light from the object O into the eyes. It can easily be seen that the disparity of views will be greater

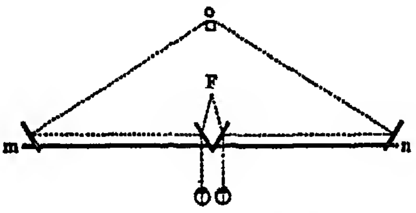


*Fig. 34.* Telestereoscope. (From Bills, General Experimental Psychology, Longmans, Green & Co.)

than in the case of normal vision, the horizontal distance from $m$ to $n$ being greater than the interocular distance.

Perspective effects much superior to those possible in ordinary photography may be obtained by taking two airplane views of a distant topography from positions fifty or more feet apart. When combined stereoscopically many details are disclosed which would otherwise be impossible to record. Studies of this sort have been made of supposedly unscalable rock walls in the Grand Canyon, disclosing ledges and handholds which are invisible in the flatter and less revealing fields of telescopes.

Other devices exist whereby the disparity of images may be reduced to the point at which binocular vision is very nearly the same as monocular, i.e. little or no stereoscopic effect is present. With these instruments, along with the telestereoscope, or with the stereoscope alone, the stated principles of the relationship between retinal stimulation and the depth experience may easily be demonstrated. The effects of interchanging stereoscopic figures was previously noted. Inversion of the retinal disparity by "switching" the image which would normally fall on one retina to the other, produces an inversion of the depth effect. By means of an instrument equipped with reflectors objects may be seen in this way. Convex surfaces may be made to appear concave, for example. When two objects at different distances are viewed, the nearer is seen as the farther, the farther as nearer. The effects of monocular signs may easily overcome this so-called "pseudoscopic" phenomenon, however; in the last instance overlapping of the farther object by the nearer will

prevent the illusion and cause things to be seen as they are. Thorough familiarity may also overcome the illusion; reversal of the images of a human face, for example, will not cause it to appear concave, habit being too strong a factor.

As was mentioned before, the whole of the depth impression received with the stereoscope is not the result of pattern disparities. A certain amount of it is the result of the *monocular signs* in the drawing or photograph itself, the degree depending on the number of such cues present. This is the *perceptual* depth effect obtained when any representation on a flat surface is seen with the naked eye. The third dimensional impression is weakened in such cases by any factors which increase the surface visibility and thus emphasize the fact that this surface is flat. Standing too close to a painting will do this, as is well known; likewise illumination which is too strong and direct. The stereoscope merely adds, to the visual depth impression accruing from the monocular cues, the supplementary visual depth consciousness generated by image disparity.

It is the fact that stereopsis reinforces the monocular effect that makes binocular distance judgments more accurate than monocular for near objects. Wundt suspended a black silk thread vertically in front of a tube through which the observer saw it against a distant white ground. The distance of the thread was varied between successive fixations and the observer was asked to report the nature of these changes. Binocular distance judgments were found to be from 2.5 to 4.5 times more accurate than monocular estimates under these conditions. More elaborate experimental studies have shown that binocular judgments are less variable as well as more accurate, and the fact is attributed to the influence of disparity. The acuity of depth judgments with binocular vision may be remarkably great. Helmholtz found that with three needles placed vertically in the same plane at a distance of 34 cm., a movement of one of them .5mm out of line was detectable.

The comparative superiority of binocular judgments may be roughly demonstrated by a familiar experiment with the fingers. Hold the right forefinger up about 20 inches from the eyes; also the left forefinger, pointed downward at arm's length and so that the tips of the two fingers are about an inch apart. Now close one eye and bring the farther finger inward until

it appears to be located directly over the nearer one. Open the closed eye and check the judgment. More striking results may be obtained if pencils are used and if another person manipulates them.

In order to function as signs of distance, visual characteristics of objects must vary as distance varies, in such a manner that they may be used as substitutes for direct knowledge of different amounts of space. It was noted that size, brightness, detail, etc., clearly fulfill such requirements. Since the difference between the two patterns of retinal stimulation likewise varies regularly with distance, this factor might seem to fit in logically with the monocular criteria so far as mode of operation and perhaps development are concerned except for one fact: that the image differences are not conscious experiences under normal conditions of vision. The statement that we are "not, ordinarily, aware of the monocular signs" either, until attention is specifically directed towards them is not in the proper sense relevant here. These signs are clearly observable if we stop for a moment and shift our interest from our space-perceptual responses to their stimuli, but we are unable to become conscious in a similar fashion of the unlikeness of our visual images, when such exists. We have to view a near object through alternate eyes to appreciate this fact. With both eyes open consciousness contains a single impression, homogeneous in perspective and markedly three dimensional in extension.

In case of the monocular signs, then, the stimulus registers in consciousness (though not ordinarily attentive consciousness) as well as the response (i.e. the spatial percept). In case of the disparity factor it does not; only the psychic resultant of this kind of retinal stimulation is observable. Stereopsis is demonstrably present early in life, but it is not yet known how disparate stimulation produces it.

A final binocular visual factor may be briefly mentioned. If a finger is held a few inches from the eyes and fixated, a second finger held farther away and directly behind the first will be seen double. If the farther finger is moved toward and away from the nearer, the distance between the two images will decrease and increase proportionally. If the farther finger is fixated the nearer will likewise be seen double, and the

distance between the images in this case will increase and decrease with movement towards and away from the eyes. In fewer words, the distance between the double images will increase as the object moves away from the fixation point, whichever finger it happens to be, and diminish when the object moves toward the fixation point. Here again is a visual impression which varies regularly with the distance of objects and therefore has the first requirement of a sign.

Since, however, the distance between the images increases both when the object producing them approaches the observer and when it recedes from the fixation point (in case of a nearer and a farther object respectively), the question naturally arises how such a fact can be an unequivocal sign of distance. It has been suggested that the distinguishing factor is that when the images result from an object farther than the point of fixation they are uncrossed or "homonymous," i.e., the image corresponding to the right eye is on the right in the visual field, while that corresponding to the left eye is located on the left. On the other hand the images produced by an object nearer than the point of fixation are crossed or "heteronymous," meaning that the above-stated relationship is reversed, the right eye's image being on the left in the field, and the left eye's image on the right.

According to this suggestion homonymous images are a sign of a more distant object, and the amount of space between the images tells how much more distant. Heteronymous images signify a nearer object, and the space interval tells how near. The theory assumes that depth perceptions are made on this basis. "If—it can be assumed that the difference between homonymous and heteronymous double images is a difference which affects perception—though it is not a difference of which we are consciously aware—then this difference would enable the observer to know whether a doubly seen point were nearer or farther from the eye than the point on which the eyes are fixed.[121] It seems doubtful, however, whether a fact unknown to the observer, namely, the difference between homonymous and heteronymous images, can validly be classed among the visual signs of distance.

A more plausible suggestion is that the location of double images is judged on the basis of such monócular cues as size,

overlapping, etc. In this way we are made aware of the relative distance of the objects which these images represent. Our distance consciousness of these objects would thus be based on the same signs which aid our perception of the distance of the object of fixation. It may be concluded that double images, so far as they enter as signs at all, do serve to inform us of the location of objects indirectly seen. They contribute to the general spatial setting or frame for more refined percepts of those objects which occupy the focus of our interest—the objects directly fixated.

## CONVERGENCE AND ACCOMMODATION

There are two main groups of factors involved in space experience on an ocular basis. One of these comprises the various forms of retinal stimulation just discussed. The other is non-retinal and is associated with certain sensory data connected with the motor adjustments necessary to the fixation and focussing of objects. The general formula so far illustrated in the case of the monocular cues—that a distance sign must vary systematically with the distance signified, applies further to accommodation and convergence, since it is known that these functions are specifically specialized to adapt to various spatial locations of the "object of regard."

A relation between ocular muscle sensations and distance perception was suggested centuries ago. Berkeley stated that, ". . . it is certain—that when we look at a near object with both eyes, accordingly as it approaches or recedes from us, we alter the disposition of our eyes, by lessening or widening the interval between the pupils. This disposition or turn of the eyes is attended with a sensation, which seems to me to be that which in this case brings the idea of greater or lesser distance into the mind." Berkeley believed that this relationship was an acquired one: it is ". . . because the mind has, by constant experience, found the different sensations corresponding to the different dispositions of the eyes to be attended each with a different degree of distance in the object—there has grown an habitual or customary connection—so that the mind no sooner perceives the sensation arising from the different turn it gives the eyes, in order to bring the pupils nearer or farther (apart), but it withal perceives the different idea of distance which was wont to be connected with that sensation."[122]

The associated reactions of accommodation and convergence, being mediated by muscles, are a source of kinesthetic sensations which vary, in amount, inversely with the distance of objects, at least for relatively near positions. We thus have here another sensory factor but one associated in this case with ocular muscles instead of with the retina. A number of experiments have been performed to test the assumption that distance judgments are possible solely on the basis of this factor. In order to do this all other factors must be either eliminated or held constant while those being tested are varied. As the distance of the test object is changed there must be no concomitant changes in its size or brightness. All other monocular criteria must be

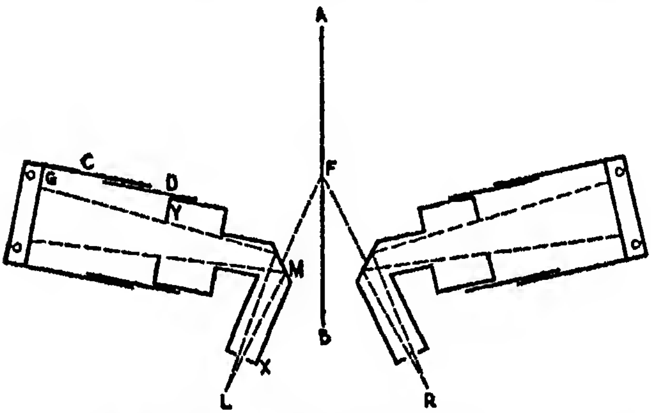


*Fig. 35.* Carr's mirror stereoscope. (From Carr, Introduction to Space Perception, Longmans, Green & Co.)

eliminated, as well as the factor of disparity. A mirror stereoscope devised by H. A. Carr of the University of Chicago and used by Swenson,[123] succeeded in meeting these requirements. The instrument is represented in cross-section in Figure 35.

It consists of two telescopic tubes (pointed in opposite directions) each making an angle of a little less than 90° with the smaller tubes serving as eye-pieces. The eyes are located at points *L* and *R*. Considering the left half of the instrument: *G* is a glass screen illuminated by the small bulbs behind it. The screen is the visual object. The transmitted light is reflected into the eye by the mirror at *M*. *C* and *D* are adjustable sections of the tube. Since the distance of the screen may be

altered at will, accommodation may be varied accordingly and without affecting convergence. The visual axes must be converged upon *F* in order to fixate the centers of both screens. The observer then sees a single luminous circle located at *F* (or some point on the line *AB*, as convergence is varied). *Y* is a disc with a circular aperture whose distance from the mirror *M* does not vary.

While the amount of visible surface area of the screen will diminish as it moves closer to the eyes, the size of the retinal image will remain constant, since it depends on the size of the aperture at *Y*. Moreover, as the screen approaches, proportionally less light will enter the eye, since less of the screen's surface is visible. (Means were taken to eliminate light reflection from the walls of the tube.) In this way both size and brightness were held constant for different distances of the screens, i.e., different adjustments of accommodation. The tubes can be rotated for various degrees of convergence; the visual axes can be directed to any point along *AB*. The character of the rotation is such that the distance between the eyes and the screens remains constant during different convergent adjustments. Accommodation and convergence may thus be varied independently of each other.

A calibrated rod was placed at *AB* with a sliding marker which the observer moved until he estimated it to be at the position at which the visual object appeared to be located. This distance was then compared to the actual distance for which convergence and accommodation had been adjusted in advance. The comparison disclosed whether or not accurate distance judgments could be made on the basis of these two reflexes.

Swenson found that the associated factors of accommodation and convergence are highly effective as a basis of distance perception within a range of 25-40 cm., the range within which the study was made. The average error of the judgments as compared with the true distance was less than 1 cm. It was also found that when accommodation and convergence were adjusted to different distances (i.e., dissociated) the object was judged by the observer to be located at positions intermediate between those recorded when the reflexes were adjusted for the same distance. Both factors are therefore effective, but since the object was judged nearer to the convergence point than

to that of accommodation, convergence was indicated to have the greater influence.

Both reflexes occur in monocular as well as binocular vision. The presence of convergence can easily be detected by touch with one eye closed, as fixation is shifted. The two factors would thus be classed as "monocular and non-retinal" according to the definition previously given. The greater accuracy of binocular distance judgments as compared with monocular is to be attributed to the disparity factor. The effective operation of all of these is confined to relatively near distances; less than 50 feet, according to Carr.

There are other ways of isolating these factors. A star may be viewed with the telestereoscope previously described. Accommodation and parallax are eliminated at this distance; the size and intensity of the image are constant. The angle of reflection of the light may be varied by rotating either pair of mirrors. Convergence will vary correspondingly and as it does so the star appears to move toward or away from the observer. Again, in the unusual case of an individual who was able to vary accommodation at will while holding convergence constant, a fixated object could similarly be made to appear to move forward or backward. The object remained single during these movements, though its clearness varied. Objective examination showed that the image advanced as accommodation was increased, and receded as it was relaxed.

Returning for a moment to the issues discussed at the beginning of the chapter, it may be noted again that the final word has yet to be said on the matter of visual space origins. Among the older authorities some believed space consciousness to be wholly dependent on experience; others, that while the spatial frame of visual data is natively given, the accurate localization of objects is an ability which must be learned. It is generally agreed that the reaction to the monocular visual criteria is one which involves meanings, i.e., is perceptual in nature, as the term has been used in the text. These criteria are the only ones operative for objects beyond the far limits of convergence. Within this limit binocular parallax and the stereoscopic effect

are of increasing importance. Stereopsis has been found present in children three years of age. Distance judgments on the basis of innate organization have been observed in some species of lower animals. Such a basis is therefore at least possible. On the other hand there are solid grounds for pressing the experience interpretation as far as it will go. The fact that the spatial aspect of visual impressions seems to inhere in them with the same immediacy as do color and brightness has long been recognized as no proof of a native basis. There are too many examples of highly similar reactions—of which language percepts are perhaps the clearest—in which the experience interpretation is accepted. The point has been emphasized repeatedly since Berkeley's time; Helmholtz insisted upon it, as have more recent writers. It may be illustrated a bit further in another feature of visual space experience.

We instantly and "naturally" see a sounding object, e.g., a clock, at the same place from which its sounds issue. The visual and auditory experiences have the same source. When a person speaks to us we see the lips move, hear the words, and locate the sounds as issuing from the lips. Vision and touch are similarly related. The spatial location of a pressure on a limb is the same for vision as it is for touch. We *see* the object on our skin at the same place that we *feel* it. The question to be raised is whether there was once a time when two such experiences were wholly unrelated—when no connection was perceived between the sight of a touching hand and the experience of pressure; between the sight of the clock and the sound of its chime. From the fact that post-cataract cases are unable to identify visually objects which are familiar to hearing, it may be inferred, at least, that such ability to locate, for example, verbal sounds and the visual impression of lips at the same place, would be absent.

The classical experiment of Stratton threw a very interesting light on the problem. For a period totaling nearly 90 hours he wore a system of lenses which inverted the visual field both horizontally and vertically. The field was rotated through 180°. No light entered the eyes except through the lenses. All objects were seen upside down. Those in the upper field were seen below; those at the right were seen at the left. An object touched was seen in one place and felt in another; a sounding

body was heard in one direction and seen in another. A falling object, for example, was heard in one place and its contact with the floor seen elsewhere. The feet and floor were seen above and felt below. An extended hand felt moving to the right was seen moving to the left.

Visual-motor coordination was of course badly disrupted. The simplest movements had to be studied and accidents were frequent. Gradually, however, a new system of coordinations developed, and a new habit of localization. Auditory and touch impressions became associated with the new visual pattern. The sound of a hand's contact with an object came from the place where the hand was seen. The tapping of a pencil seemed to come from the visible pencil. The feet were *felt* to strike on the floor where they were seen, though they were seen above the head. Their sounds likewise issued from the point where they were seen and felt. In general the location of all impressions of sound, touch and pressure came to coincide with the visual features of the heard and felt objects. Moreover the new localization system finally became familiar and effortless. The visual world which must first have been heavy with the atmosphere of illusion became substantial and real as effective coordinations between vision and touch became habitual. The results point to the probability that the normal coordinations are likewise developed with experience, however "natural" they may seem to us as adults. This quality of reactions is definitely no safe guide in the problem of origins.

A generalization which may be drawn from the discussion of this chapter is that effective perceptual reactions may be made despite considerable ignorance on the part of the reactor as to the stimulus basis of his responses. A person may be a good judge of distance and still be unable to state in any definite way *how* he makes his judgments. Assumedly, of course, he could partially analyze the situation without much trouble. Size, clearness, brightness, visibility of detail, etc., are fairly obvious as distance criteria. The fact remains, however, that we seldom do stop for such analysis and need therefore to be informed as to the nature of the signs which in reality we

have been reading all our lives. Typically we react to the total visual impression of a landscape; our space consciousness is an integral part of our awareness of color, line and contrast, meanings of objects, etc., as a whole. There is no reason, ordinarily, for an attempt to discern which of the innumerable visual impressions are those which mediate depth and distance knowledge. We are conscious of these impressions, of course, but we do not single them out as signs. Sheer awareness of them as unmarked parts of the visual field is the sole condition necessary for their operation in arousing the appropriate percepts; we do not need to identify or acknowledge them in any way. Here, as in the case of language reactions, it is the response which is foremost in attention; the stimulus need not concern us. Whether the concern is practical or esthetic, it is the way we know things or the way we feel about them, not the grounds for such knowing and feeling, which sufficiently occupy our time and interest.

There are other instances of perceptual reactions in which the stimulus is not isolated and recognized. We feel that a certain individual is untrustworthy, for example, but "don't know why." We are sure that he is lying but are unable to state exactly on what basis in behavior our conviction rests, unless, perhaps, we resort weakly to such obscure resources as "intuition." It has been suggested that such instances are often merely further illustrations of the potency of unidentified stimuli. Social percepts occasionally exhibit the same trait as spatial ones; signs need not be explicit in order to call forth meanings. Certain facial "gestalts," difficult to analyze or describe; certain slight and fleeting expressions of thought, mood and feeling: these may serve in subtle ways as the triggers for percepts without being clearly located and labeled. The process of stimulus-reduction may proceed to remarkable lengths in refining such cues and lowering their visibility.

## VISUAL PERCEPTION OF MOTION

The perception of motion, being the perception of change of spatial location, may be properly discussed in this chapter; change of location, like location itself, is a spatial fact. The visual changes underlying our perception of nearness and farness, e.g., size, brightness, clearness, obviously serve as signs of motion in the third dimension. Continuous and orderly changes

in these signs are associated with the steady approach or recession of objects.

Horizontal motion must also have its signs. It may be perceived in the absence of signs only by inference, as when a moving car momentarily disappears behind a house and reappears again on the opposite side; we infer that motion has been continuous though we have not seen it. When the object is in view constantly it will be perceived as in motion only provided there are certain unmoving points of reference. All movement, as has been so often observed, is relative; actually we are all moving through space at high speed as the earth turns and as it circles the sun, but we are not aware of this because of the absence of any perceptibly stationary object near enough to serve as a reference point. If everything moves nothing moves, perceptibly.

Granted certain points of stability, then, movement will be perceived when a *serial stimulation* of the retinal receptors takes place, as when a bird flies across the visual field when our eyes are fixed on a motionless object. If the flight is from left to right, a row of receptor organs will be excited in a rapid succession extending from right to left across the retina. The perception of continuous motion is in this case the result of a continuously moving object, but the stimulus need not necessarily be of this sort. The same experience will occur with stationary stimulation if the retinal receptors are aroused in the necessary rapid succession. Advertising signs consisting of a pattern of electric bulbs which flash on in series furnish very effective motion impressions.

In the above situation, with the eyes at rest, the larger portion of the field is stationary; we are conscious of this as the bird's image passes. However, our perception will be substantially the same when we follow the bird with our eyes, though the stimulation will now be quite different. The bird's image will remain approximately stationary on the macular area while the light rays from the remainder of the objects in the field will sweep across the retina. The stimulus-pattern is reversed, in this case, but the experience is the same: perception of an object in motion, except that consciousness of the moving object is now central and clear, whereas previously it was chiefly a marginal impression. The background is now supplying a moving stim-

ulus, relative to the retina; it is *perceived* as stationary none the less. Our experience checks with the objective facts, not with the character of retinal stimulation. Numerous instances of this type of phenomenon were described in the preceding chapter.

From the foregoing it appears that change in the position of the eyes is as important as change in the position of the retinal stimulus in determining the character of motion experience. A retinally stationary stimulus may evoke the percept of a stationary or a moving object, depending on the behavior of the eyes and of the rest of the visual pattern. The nature of the ocular adjustment alone would conceivably be an adequate clue, the position of the head and body being known. When we visually sweep a landscape without making any fixations there is no *relative* change of visual positions; the entire retinal stimulation pattern changes, yet we perceive all objects as at rest. The importance of kinesthetic sensations from the body, neck and eyes is clear; vision and kinesthesis must cooperate.

Even when the body itself is in motion our perceptions seldom fail to check with fact. As our train begins to move forward out of the depot, for example, a stationary train on the adjacent track moves backward visually. We are aware of ourselves as moving. Yet the visual situation is identical when the adjacent train begins to move backward, our own train being stationary. A familiar illusion sometimes occurs in this case, but more often it does not. The usual correctness of the motion percept is the result of the supplementation of the ambiguous visual signs by other sensory impressions, such as the abrupt pressure of the body againt the back of the seat, the backward jerk of the head, the sound of the car couplings, or by simply turning to a dependable stationary visual cue,—the railway depot buildings, the platform or the people standing upon it. To the extent that such supplementary motion indices are absent will the observer be likely to err in his interpretation. Many visual stimuli evoke the motion percept but fail in themselves to tell us what or who is in motion.

Experimental studies [124, 125] have simplified the conditions under which the motion percept is aroused. Two lights are exposed in a dark room. No background of any kind is visible. The lights are moved electrically on horizontal tracks; various speeds may be used. Both lights are five feet away at

eye-level. A single light appears first and the observer is instructed to fixate it continuously; the second is then exposed and movement begins. One light is stationary, the other moves, and always away from the first. The observer reports what he sees: whether one or both lights moved; their relative speed; etc. The factors experimentally varied are the speed, the size, the fixation (the small or the large light), the direction (the moving light to the right or the left), and the location (the small light on the right or the left).

It was found that the tendency to see the stationary light as moving was greater when this light was the smaller of the two. The larger tended to be perceived as stationary, the smaller as in motion. The greater the difference in size, the greater the tendency to see the larger light as stationary, the smaller as moving. In the experiment one light was continually fixated, the other observed with indirect vision. The fixated light was the more likely to be seen as moving; illusory movement was more often associated with it. Increased speed of motion tended to increase accuracy of perception; diminution of speed increased the tendency to illusion. The remaining factors studied had little effect on the accuracy of perception. Obviously the conditions of the experiment were such as to increase the likelihood of misperception.

It is natural to reason that experience accounts for the tendency to associate size with stability. Taking the world generally, movement is more often associated with small objects than with large. Mountains, buildings, trees and houses,—these are the things that are fixed in position; human beings, vehicles, insects, balls, hats in the wind,—these are the objects that move. Aside from sheer magnitudes, experience enters the situation in that the *nature* of the object itself is a factor in movement perception. A bird or an airplane against the sky is always in motion; it remains only to judge its speed and direction. Similarly a telephone pole is by nature stationary and may thereby be used as a stable reference point in gauging other movements.

Motion may be too slow or too rapid to be perceived as such. A ship seen on the horizon does not appear to move at all, nor does the hour hand of a watch. The distance of the object is important here as well as its speed; however great the latter the object will be perceptually stationary if far enough

away. Such measures of velocity are independent of distance when stated in terms of angular units per second. The upper and lower thresholds (i.e., highest and lowest rates) of perceptible motion have been worked out in such terms. The usual values for the lower limit, according to Troland,[126] lie between one and two minutes of arc per second, increasing toward the periphery. (De Silva[127] gives this, in perhaps more familiar terms, as 0.2 cm. per second at a distance of 2 meters.) Perceived movement is greatest at the center of the visual field. When speed is too great the visual impression of motion gives way to one of blur. According to De Silva, 150 cm. per second (about thirty miles per hour) with the moving object 2 meters distant, was one report for the upper threshold of motion perception. As this writer suggests, as automobile moving at such a speed, two meters away and seen through a small window, would probably not be seen as in motion.

Motion experience resulting from successive stationary stimuli was mentioned in the preceding chapter. Other motion phenomena will be discussed in the section on visual illusions. In the present section the parts played by the shift of the retinal image, the sense of movement in the eyes, head and body, and the influence of past experience, have been briefly stated.

## Chapter VI

# ATTENTION IN RELATION TO VISION

It is often emphasized that attention, or the reactions included under that heading, are of the nature of preparatory adjustments and that they are a preparation for perception. The "state of attention" represents the organism in readiness to perceive; as such it might logically, or psychologically, have been studied previous to the sections on perception. For several reasons, however, it has been thought best to place the material at this point. Attention is a preliminary to the "intake" phase of the visual process, but it is also intimately related to the motor aspect of that process in a way which needs to be given due comment.

The term attention, it should be stated at the outset, does not introduce a new psychological reaction or capacity for reaction. It is rather merely a name, on one hand, for a quite commonplace fact about experience, and on the other, for certain responses which were outlined earlier in the text. Analyzed, it turns out, like the "will," to be not a *thing* but a class label for certain specific facts of behavior.

### THE STRUCTURE OF CONSCIOUSNESS

Stated conventionally and as simply as possible, it may be said that of all the items we are conscious of at any given moment, some one or few enter more prominently, vividly and clearly into our awareness than the rest, and these are said to occupy our attention, or to be given attention, or to be the things of which we are attentively conscious. If the term "field of consciousness" be used to include all the sensory and perceptual impressions (sights, sounds, pressures, temperatures, etc.), all of the feelings, emotions and thoughts of which the reader is at this instant to any degree aware, then the "field of attention" will include only those which are central in clearness,

which are strongly and sharply in focus. The meanings contained in this definition will here assumedly occupy the reader's attention or attentive consciousness. Other things,—the sounds from the street or from a near-by conversation, will be in the field of consciousness but not in the smaller field of attention. He is aware of these things but not attentively aware of them. Still more faintly, less clearly and prominently, he is aware of the weight and pressure of the book in his hand, of a postural stiffness, a pang of hunger, a stir of restlessness or the approach of fatigue. These things occupy the margin of his consciousness; they are in the background. They constitute a vague context or frame extending indefinitely around the bright main focus of the present moment of experience. The terms used above may already have suggested a description of the visual field, which has often been used as an analogy in this connection. The opposition between visual foreground and background; center, and margin or periphery, is a familiar one to students of vision. Attentive consciousness or attention may be said to bear a relation to the field of consciousness in its entirety similar to that which the macular field bears to the total field of vision. Consciousness, like vision, has a structure which is best described in terms of relative clearness.

The meaning of the term "clearness" is rather peculiar in this usage. It does not necessarily mean strength or sharpness of the impression itself. The voice which we "strain our ears" to hear over the telephone may remain faint and indistinct. Simply, our impression of the sounds, poor as it is, is nevertheless central in consciousness; it is relatively more vivid than anything else; more distinct and focal even than the perhaps much louder sounds which we hear but are "inattentive" to while telephoning. Description of consciousness in terms of degrees of clearness applies rather to the form of consciousness itself than to the quality of the contents which occupy it. Our own thoughts are intrinsically weaker in vividness and in sharpness of contour than our sensory impressions, speaking generally, yet there are times when everyone is "wrapt in thought," when preoccupation with these faint and comparatively unstable things shuts out the external world, and makes a mere background of "reality" itself.

Consciousness, therefore, is a limited activity. We must be inattentive to many impressions while clearly aware of one or a few. As we view a landscape we may think that we take it all in at once, that we see it all clearly, but examination shows that the eye shifts rapidly and continuously from point to point, and that at any moment only a very small area of the total visual expanse is given as a clear visual impression. And just as the eyes move about over the visual field, "attention" wanders over consciousness, selecting now visual impressions, now auditory, olfactory, tactual, etc., as its temporary occupants. Some lack of agreement exists as to the exact structure of consciousness in respect to clearness. Some introspectors report that a marked boundary exists between the center and the margin of the field, but there are two main levels of clearness. Others do not find this boundary so definite; they report that clearness shades by degrees from maximum to minimum. It is possible that individual differences exist in this respect.

The first important fact, then, is that consciousness is not uniform or "all of a piece" in character. Its center is clear, relatively; its margin vague and weak. Moreover, the values of the field in respect to clearness may vary in distribution. At certain times the *spread* of attention is greater than at others. There are moments of relaxation when the mind seems impartially open to almost any impression; the field of clearness expands to include an unusually large number of items. Interest is diffused instead of focussed and we take in many things because we take in very little of each one; attention is broad in scope because shallow in depth.

The opposite sort of disposition occurs when attention is strongly and narrowly centered upon a single point. During extreme absorption or "concentration" one group of impressions becomes very clear, and to the extent of its growth in clearness others become correspondingly obscure until a sharp degree of contrast obtains. The more acutely in focus the center of the field, the more vague and sketchy the margin, as though there were just so much "attentional energy," and its marked convergence upon one group of data entailed a proportionate withdrawal from all others. The concept is sometimes illustrated with instances of the extreme preoccupation which often accompanies the mental activity of genius. So profoundly, or rather,

perhaps, so *much*, does the attention of a Newton or a Gauss become drawn into the vortex of mathematical calculations that little is left for ordinary distractions or even for fairly high degrees of hunger and fatigue. It is possible that the total amount of "attentional energy" remains approximately constant, varying simply in the ebb and flow between center and margins.

A point to be emphasized here, of later importance in connection with the visual reflexes, is that within the roughly circumscribed limits of attentive consciousness itself degrees of clearness may be represented. Giving attention, that is, does not always mean the same thing. The object in which we happen to be but mildly or casually interested in will be *relatively* the clearest while we attend to it, but this will be a lesser degree of attention than that represented by the intense absorption previously mentioned. Whether described as weak or strong, attention refers to what for the moment is the most vivid portion of the conscious field.

Another characteristic of attention is its *unity*. If it is thought of as the focus of consciousness it may be said that there is never more than one focus. Attention to one thing means relative inattention to all others. Two conscious contents, unlike and complex, cannot simultaneously be apprehended with clearness. Even in conversation with a person we cannot include within the same focus a careful scrutiny of his face and manner along with close comprehension of what he is saying. No more can we fully comprehend both of two people who talk to us at once. Reported cases of the simultaneous performance of two operations usually turn out to be the result of the alternation of attention between activities at least one of which has become fairly thoroughly automatic. The latter then runs along with little supervision while the other is conducted within the primary focus. Try, for example, some simple multiplication while reciting the alphabet. In the same way auto driving or piano-playing may be carried on effectively during a conversation, by experienced performers. So called absent-minded behavior is of this character although the term is usually applied to cases in which the automatic activity is somehow inappropriate to the situation. Very frequently, for example, we undress at night with our attention centered in

conversation or reverie; the sequence of movements can run its course in a completely automatic fashion. It is when, however, we deliberately begin only to change an item of clothing, transfer our attention to something else and discover later that the first act has set the rest of the disrobing sequence into operation, that we are said in a popular sense, to have acted "absent-mindedly." It is the unsuitedness of such behavior, rather than its involuntary character, that distinguishes it.

## THE SPAN OF THE ATTENTIVE ACT

A classical problem in connection with visual attention is that of its range or span, *i.e.*, the question as to how many separate impressions can be grasped simultaneously by a single "act" of attention, all being included in maximum clearness. Or, to put it differently, how many items can be included in an act of attention without reduction of the clearness which each item would exhibit were it presented by itself. A device is used in these experiments which permits the exposure of a visual target for a very brief interval. The items on the target may be a number of dots, letters, numerals, words, or even sentences. The exposure must be too rapid to permit time for eye movements, since this would mean more than one attentive act. The target must also be small enough to be included within the approximate limits of central vision, since the experiment is designed to gauge the limits of the attentive grasp rather than those of the field of visual clearness. The question is how much of what the eye clearly presents the mind is able to receive.

The interesting fact disclosed by these investigations is that the number of items grasped depends chiefly on their organization. Only three or four letters can be taken in as separate things, but many more than this if the letters are grouped as words, since a familiar word of three or four letters is seen as a unit. Finally, as many as fifteen or twenty can be caught if organized into a very familiar sentence or phrase. It will be noticed that the units are perceptual in the latter instances; the general *form* of the word or phrase is adequate to arouse its meaning. Words are often more accurately identified than single letters, the words being more familiar. What is reacted to as a unit is determined by experience, rather than by the physical composition of the unit itself. We do not need to distinguish each letter of a familiar five-letter word in order to

grasp it as a unit. It is therefore doubtful whether the actual scope of attention is increased by the organization or grouping of items into familiar and perceptually unitary wholes. The units are to be defined in psychological rather than physical terms.

It is fairly well agreed that five or six units constitute the limit. With three or four dots on a test card the number will be correctly reported every time. As the number of dots is increased the errors mount steadily until the results for ten or twelve begin to suggest guessing. Individual differences are often marked. For scores beyond five or six the factor of grouping is very important. In case of eight, for example, if the dots do not instantly fall into familiar number groups, they will not be correctly counted, but if seen as two units of five and three the response is easy. The term "count" here does not mean literally an enumeration. It is rather a naming reaction; four dots are *read* as four in the same way that a familiar word is named. It will be seen that the results in such cases depend importantly on the preliminary arrangement of dots on the test cards. If closely clustered they will be difficult to pattern into sub-units. Results also depend on the character of the reaction. If letters are to be named, four or five will be the approximate limit, which may extend to eight or nine if only the number is to be reported.

Similar results are obtained for hearing, suggesting a general mental law applying to this function. Eight ticks of a metronome can be grasped in the same manner as dots, the number increasing greatly if the impressions can be grouped. Thus eighteen ticks can be taken in as easily as six if rhythmically patterned into units of threes. (Titchener suggests a significant agreement between this fact and the technique of musical and poetical composition: the limitation of musical phrasing to no more than six measures, of verse-lines to no more than six "feet." Larger musical or poetic units cease to be psychologically unitary.[128]) Immediate memory, or "memory after-images," in the latter case function to make the experiment quite similar to those involving the simultaneous presentation of stimuli. It has been suggested that this factor may in some cases play an important part in the matter of visual attention. A vivid memory-image of a group of dots might persist long

enough to make possible an actual counting. However, the primary determinant, it seems generally agreed, is the process of perceptual grouping or organization.

Beyond this, the span of the attentive act, as well as the amount of available attentive energy, appears to have fairly well-defined natural limits. Little is known of the neurological conditions underlying these phenomena. It seems logical to assume the existence of gradients of physiological function which parallel and express in the characteristic structure of consciousness, i.e., something amounting to a focus of cortical activity, an area of highly energized neural patterns environed by others at lower activity levels. Such an hypothesis is obviously *a translation of the focus-margin relationship into terms* of cerebral dynamics. The approximate locale of such a focus has been suggested in the frontal lobes, the supposed seat of introspective consciousness. Piéron,[120] on the other hand, believes that any attempt to localize attention in any part of the brain (like seeking the seat of intelligence) would be something like trying to locate the productivity of a machine in some one of its parts.

## THE MOTOR ASPECT

Attention has so far been described solely on its subjective side, as a fact about the structure of experience. It has also a number of objective features, its motor side. Most conspicuous of these are the special adjustments of the sense organs. Those involved in vision have already been outlined in some detail. Clearness was emphasized as the primary characteristic of attentive consciousness. Clearness of any type of sensory experience depends partly on the receptor itself.

The retina varies greatly in sensitivity; one of the first requisites for a clear and sharply structured visual impression of an object, therefore, is that the stimulus shall be brought to bear upon that portion of the sensory surface best able to supply such an impression. The intensity of the image will be maximal only when the light rays impinge upon the macular area. Its definition will be maximal only when a close approach to a point focus of light upon this area is obtained. The field of consciousness that psychological optics is mainly concerned with is the field of visual consciousness, and the *attentive* portion of this field is normally that corresponding

to macular stimulation. Clear or attentive vision in relation to any object is obtained, accordingly, only when the eyes achieve macular fixation and high focus for that object, and version, convergence and accommodation are plainly designed to this end. Most of the receptors for external stimuli exhibit such preparatory adjustments. Movements of the tongue and lips in tasting; sniffing to increase the passage of air through the nostrils in smelling; exploratory movements of the fingers in "feeling" an object; "hefting" an object in order to judge its weight; all of these are designed to clarify and intensify sensory impressions.

More general adjustments contribute to the same end. In the attitude of intent listening or visual scrutiny the body as a whole is not only motionless but exhibits a certain degree of rigidity. Breathing may momentarily cease or become shallow. Pulse rate may increase at these times. The checking of irrelevant movements is characteristic. The quietness of an audience is due to the involuntary inhibition of such movements, and the amount of noise in such a case is a fair index of collective attention. The same immobility, or tendency toward it, is manifested when attention centers upon thoughts. All such general adjustments either remove possible sources of distraction or else contribute positively to sensory orientation, as when we turn the body and the head to assist visual fixation, or tilt the head in the direction of a faint sound. Attention has both facilitative and inhibitive aspects. In increasing muscle tension or tonus throughout the body it prepares for movement; at the same time all specific movements are inhibited with the exception of those involved in sensory adjustments. These facts definitely point to the characterization of attention as essentially a preparatory reaction.

## FORMS OF ATTENTION

In descriptions of the forms of attention the distinction between voluntary and involuntary has always been prominent. Since it has a bearing on the visual process which will later be mentioned, a few words may be given it at this point. *Voluntary* attention is sustained by force or effort; it is accompanied by a sense of strain or tension. The student striving to rivet his thoughts on his book, reining his mind away from impulses toward recreation or reverie, is a common

illustration. Voluntary attention accompanies, in various degrees, the doing of anything that is done when one would rather be doing something else; things done as means to an end rather than as ends in themselves. It is associated with things done because it is felt that they ought to be done, not because one wants to do them. Activities driven by voluntary attention are therefore more or less unpleasantly toned in feeling-quality. They must be supported against the pressure of competing thoughts and impulses and despite the absence of any immediate compensatory pleasure for the labor expended. Attention is a form of psychological reaction, an act or activity which is voluntarily controllable in respect to its direction and its degree, and it may therefore be exercised in a way counter to the influence of other impulses, just as one can keep a limb extended during the medication of a wound, inhibiting strong tendencies to withdraw it.

*Involuntary* attention exhibits strongly contrasting features. All sense of strain and pressure, of competition and struggle, is absent. It accompanies the spontaneous doing of things enjoyable in themselves. The case of a reader lost in the excitement of a fascinating adventure tale, borne along swiftly from event to event, jealous of intrusion, oblivious to otherwise distracting stimuli, is an example differing markedly from our earlier illustration. Involuntary attending is a free-flowing activity sustained by interest and the pleasure accruing from the satisfaction of interest, partial or promised. The mind is here exclusively fixated upon the subject of interest, with no expenditure of concern or even consciousness upon the process of fixation itself. The transition from voluntary to involuntary attention depends on an awakening of interest in a thing "for its own sake." As the study of a new material begins, the attentive reaction may entail much forcing; the labor is performed in the service of some motive other than interest in the labor itself. Later, with a context of knowledge developed, interest and pleasure awaken and attention gradually becomes involuntary and self-propelled.

A primary requirement for sustained attention is *change*. Attention cannot be fixed at one and the same focus for more than a few seconds at a time. It is a highly mobile and rest-

less mechanism. What is commonly meant by prolonged or fixed attention is attention which moves continuously but in the same direction or within the same field of content. Hours may be devoted to a single problem but during this time the mind is roving constantly from thought to thought, marshalling relevant associations, examining each facet and detail of the issue, viewing the whole from every angle. It is when this flux ceases that attention begins to wander; it is when we become hopelessly "stuck" and no new alternatives and possibilities suggest themselves that distractions become potent and we get "off the track." William James many years ago emphasized the importance of change in his comment on the notion that sought to explain genius as merely an extraordinary capacity for prolonged concentration. It is not concentration that makes genius, he believed, but rather genius that makes concentration. It means not superior capacity for attentive fixation itself, but rather an intellectual sagacity which by rapidly and frequently discovering new insights, disclosing new relationships and new glimpses of novel possibilities, keeps the mind focussed simply by keeping its contents moving and changing, in short, by keeping *it interested.* There is a feeling-quality in such absorption which distinguishes it sharply from the labored strain of voluntary fixation.[130]

## FACTORS IN ATTENTION

The question now arises as to the factors which determine the *direction* of attention, and those which determine the *degree* of attention aroused, once it has been attracted? Some of these factors are located in the external environment; others are seated within the individual himself; accordingly they may be classed as objective and subjective.

**Objective.** These are characteristics of the stimulus which are effective in "catching the eye." A dozen or more of these are supplied by various writers; without taking pains to be exhaustive such characteristics may be listed as size, intensity, change, color, repetition, suddenness, and "striking quality." The meaning of the stimulus characteristics listed will be fairly apparent. Other things being equal, the larger, brighter and more colorful of a number of objects will be the more likely to draw our attention—will have an advantage in competing

for ocular fixation. The place and importance of most of these factors is best illustrated in the field of advertising—in some respects the applied science of attracting visual attention. Nothing about an advertisement as Poffenberger[181] says, is as important as whether or not it can catch the eye; all else depends on this. Far from reading every advertisement in a newspaper or magazine, no one even sees all of them. Those that are seen must in some way stand out from the rest. The field of vision is large but the field of attentive fixation is small and the problems of controlling its movements have given rise to many investigations and enormous discussion.

As a case in point, the factor of size has been elaborately studied and found to be governed by a law of diminishing returns. The larger the advertisement the better its chance of being seen, but increase in attention value lags behind increase in size. The psychological effects of size-increase appear to vary approximately as the square root of size-increase itself. A quarter-page is about one half as good as a full page. Studies of color have given results emphasizing the importance of change. Enormously increased commercial returns from the use of color are reported in cases in which color was *rarely* present, e.g., in mail order catalogues in which the great majority of displays are in black and white. In general, as the use of color increases, its value in catching the eye diminishes, and percentages have been given indicating the amount of color which can safely be employed without too great a reduction of its value. Too much repetition of any stimulus leads to monotony and loss of attention. We cease to see and hear ever-present sights and sounds; we become aware of the clock-tick only when it stops. Custom stales the appeal of any object, however initially striking; thus the continual striving for novelty in advertising, and the great value of "new ideas."

Change is therefore regarded as the most important of the attention factors in this group. However large, bright and colorful the stimulus it soon ceases to draw the eyes unless some new feature manifests itself. A certain degree of suddenness, moreover, must accompany change. A marked increase or decrease in illumination will not be noticed if sufficiently gradual. Motion has high attention value; it has been

suggested that nature has made us especially sensitive to visual motion since in more primitive life it is among the first signs of danger. Mechanically moving window displays; electric signs giving the illusion of motion, have an advantage over stationary figures. Physical intensity is effective within limits; too brightly colored an appeal may take the eye but occupy it overmuch—distract the mind from the substance or "message" of the advertisement. The sheer sensory values must not be too forceful. "Striking quality," Woodworth suggests, is to be distinguished from intensity. Rich, "saturated" colors draw the eye more strongly than do the paler shades, although less bright than the latter; high notes are more intrusive than low. Such facts may depend upon peculiarities of sensory organization.

The objective factors are often discussed as though having an *intrinsic* appeal; the attention of the newborn infant is "naturally" caught most easily by large, bright, moving objects—by sudden, high-pitched sounds, sharp odors, etc. The potency of such stimulus characteristics seems to hold for the lower animals as well as for man. Our neural constitution is such, apparently, as to make us differentially sensitive to different qualities of the objective world. But it is not possible to explain attentive states exclusively by reference to objective factors alone. The infant whose eyes are drawn by a moving pattern of color has not the appearance of an automaton; the "mind" is responding as well as the eyes; a primitive form of interest or curiosity has been awakened. The attentive reaction is aroused by a combination of internal and external factors, just as drinking requires thirst as well as the presence of water. The objective-subjective distinction is here a "statistical" one at bottom. In looking through a series of magazine displays, for example, all observers will be affected by size and color; what is "novel" will perhaps depend as much on the individual as on the character of the display, and the same uniformity of appeal may not be achieved; a specific interest in refrigerators, fire-arms, etc., will affect few observers and thus be "subjective."

**Subjective.** Speaking generally, the subjective element in attention is comprised by the *interests* of the individual. These

may be represented by temporary or momentary purposes, as when one scans a large number of visual items in search of an eraser, a postage stamp or a name in the directory; or by permanent and fairly stable concerns, such as the interest of a professional advertising man in the make-up of an "ad." as he glances through a magazine; the interest of an interior decorator in the furnishings of a home; that of a mechanic in a new motor; of a botanist in a new flora. In such cases the direction of attention is determined primarily by conditions within the person himself; its movements may be little influenced by the presence or absence of objective appeals. The very weak sensory impression of an object one is strongly interested in may effectively hold the attention against the far more intrusive surface qualities of competing stimuli. Thus, to use an old illustration, a mother may sleep soundly through many night noises yet awaken instantly to the faint whimper of her child. The "want ad." pages of newspapers would certainly never gain the attention of readers on the basis of sensory qualities; their purpose is purely informative; attention is taken for granted and is rooted in preestablished needs of the individual.

The problem of the advertiser, once he has caught the attention, is to appeal to some one or more of the universal human interests. After attracting the eye he must arouse the mind, i.e., awaken a desire for his product. Numerous studies have been made of the relative strength of various desires and interests as expressed in responses to advertisements. This may be done by having a large number of persons grade a series of advertisements with respect to their "arousal value" and persuasiveness, or by timing the visual fixation periods for different specimens of copy. In these ways the comparative vigor of appeals may be gauged; e.g., such interests as health, family affection, safety, appetite, economy, self-improvement, personal attractiveness, sex, etc. It is not difficult to identify the basic human desires to which the displays in any commercial medium are directed. Scales of strength may be used practically in indicating which of the various human interests related to a given article stands highest in the list. An empirical knowledge of comparative preferences can be a valuable guide here.

Interests, again, may be the specialized products of training, or may be grounded in the universal "instincts." The interest of a stamp collector in a rare issue would not be classed, from this point of view, with his interest in the opposite sex, or his concern for the regard of his friends. Well developed interests and high degrees of attentiveness may on the other hand be derived primarily from specialized giftedness. With unusual degrees of innate capacity for dealing with certain features of experience, e.g., mathematical concepts or musical composition, are associated spontaneous interest in and attentiveness to such features.[132]

Interests make the mind highly selective in what it receives and retains from stimulation. The naturalist, absorbed in the identification of plant species, may be blind to the esthetic features of a landscape. In the absence of conspicuous objective attention values what we see ordinarily depends far less on what is before us than on what we are looking for. An old illustration is the question whether one is able to tell without looking whether the numerals on his watch dial are in Arabic or Roman numerals. The results are sometimes surprising. We look at watches to learn the time, not the style of the numerals; interest selects what it wants, overlooks nonessentials. Try, for example, to recall how many windows are visible from the front of a thoroughly familiar house, or how many buttons are on the coat of a person you have seen countless times. To see one must look; to hear one must listen. "Ask yourself what spots of red there are visible, and immediately various red bits jump out and strike the eye; ask yourself what pressure sensations you are getting from the skin, and immediately several obtrude themselves."[133] Expertness of any sort consists in large part of trained selectivity of attention, of knowing exactly what to look for in a problem situation. It is in this sense that an uninitiated person "does not know how to look" at a masterpiece of painting, or does not know how to listen to a symphony. Attention, almost as much as the retina, determines the character of visual experience. The terms "looking" and "listening" have been suggested as designations of the mental adjustments involved in the visual and auditory processes.[134]

## ATTENTIVE FIXATION AND VISUAL FIXATION

We may now turn from the more general discussion of attention to some of its specific relationships with vision. The statement that visual experience depends importantly upon the orientation of attention needs first a further development. The fixation of attention is a psychological reaction distinct from the fixation of the eyes. Typically the two reactions coincide; we normally give our attention more or less exclusively to the object or objects which occupy that portion of the visual field corresponding to macular stimulation. The separation of the two acts is simply illustrated in the charting of visual fields. Here the observer fixes his eyes on a point directly before him while colored targets are slowly advanced from the periphery of the field. The observer reports the position of the target when its color first becomes visible. The directions of visual and attentive fixation are in this case widely separated. The observer's eyes are pointed forward but he is "looking" far to one side; the axes of vision and attention are some 80° to 90° apart. A similar separation occurs when we look at object "from the eye-corners."

The point was interestingly brought out by Helmholtz in an investigation of binocular fusion during the instantaneous illumination of stereoscopic diagrams.[185] He mounted a stereogram (a pair of figures designed for stereoscopic fusion) on the inside wall of a darkened box. Two pinholes were placed on the figures at corresponding points of their patterns. The wall of the box was also perforated in line with the pinholes. Light from the room, entering the apertures in the stereogram, enabled the observer to see them (the apertures). By proper direction of the visual axes their light fell on the maculas and the two points of light coincided. During the instant of illumination supplied by an electric spark the figure was seen in clear stereoscopic relief. When rather complex photographs were used in this way the observer was unable to take in the entire scene at a single exposure, and several flashes were required. The significant fact to be indicated is that with the eyes immovably fixed on the pinholes, the observer was able to direct his attention in advance to any portion of the stereoscopic picture and to see primarily that portion when the illumination came. We have here a clear instance of volun-

tarily controllable changes in visual experience which are independent of any observable corresponding changes in the ocular mechanism.

Helmholtz also found that with pictures whose marked disparity made them difficult to combine binocularly, fusion could be readily obtained and held if a mental image of the solid was aroused in the mind beforehand. With some stereograms separation of the images as well as fusion was possible by an act of attention. In studies of retinal rivalry attention was again found to be a factor. If a clear idea was preformulated as to which of the rival images was to be seen, it would appear as desired, though it might be difficult to hold the attention to one of the two impressions unless some specific interest or purpose with that impression could be exercised.

Similar phenomena have been observed in the field of hearing in connection with overtones. Helmholtz first struck a note in which a given overtone was present, though unheard. He then held to his ear a resonator whose frequency corresponded to that of the overtone and again struck the note. This time the overtone was distinguishable, its volume having been reinforced by the resonator. Thereafter it could be detected in the natural sound by the unaided ear. The observer, having learned what to "listen for," was able to adjust his attention properly.

This mental act by which attention is oriented has been described—so far as describable—by skilled introspectors. A shift of mental fixation from a visual to an auditory impression is accompanied by a feeling of altered tension; a forward-projected tension is rotated, as it were, sidewise, toward the ears. The experience is easy to observe in shifting visual attention to an object in the margin of the field. The slight strain sensations are differently localized as the direction of mental movement changes. A kind of "inward-withdrawal" of the strain feeling is reported when attention leaves the sensory environment and turns to the realm of thoughts.

## ATTENTION AND THE VISUAL REFLEXES

The visual psycho-reflexes were earlier defined as reactions *dependent upon consciousness of the stimulus.* The latter, it was stated, must register its effects in visual awareness if the response is to take place. It is now time to add the vital qualification that this registration of the stimulus will not in itself

evoke an ocular adjustment unless attention is free to receive the new impression. The stimulus for version, convergence, or accommodation, that is, will evoke these reactions only provided that the object furnishing this stimulation has greater power to excite the attention than the existing point of fixation. An arousal of interest is just as essential as the light image on the retina. Innumerable stimulations qualified to elicit the major visual reflexes fall upon the retinas every hour of the day without effect. Vision always takes place in a frame or ground of marginal impressions to which we are inattentive. It is at least as often the mental response—or absence of response—that determines whether a new fixation is to be elicited by a marginal impression, as it is the color, brightness and motion of the stimulus. However rich in sensory qualities, the force of such impressions is nullified if consciousness is over-familiar with them or is otherwise occupied. The conditions of reflex excitation, then, are—in addition to retinal stimulation and awareness of such stimulation—the arousal of interest ("psychic demand," desire to see) in the source of such stimulation, and an arousal of interest, moreover, which is at least momentarily greater than that centered upon the present object of regard.

Not only, moreover, does the momentary state of attentiveness determine *whether* these reflexes are to operate, given their appropriate stimulation; it likewise determines *how* they will operate, once aroused. The delicacy and refinement with which these adjustments proceed, once initiated, is conditioned by the *degree* of attention generated by the new source of interest. A quick and casual glance at an object, providing instant recognition or identification of a familiar and indifferent visual item, does not require and does not obtain accurate fixation nor complete fusion and focus. Perfect fusion and high focus develop only when a relatively high degree of interest is awakened. With interest moderate or weak the reflexes function in a rough and incomplete way. The amount of accommodation in such cases may be only from two-thirds to three-quarters of that necessary for sharp focus of the image. With lack of strong interest there is no "psychic demand" for a clear impression, and a considerable amount of blur will be tolerated; a rough impression suffices. Maximum reduction of blur circles

occurs only during concentrated scrutiny motivated by relatively intense interest.

Similarly, with casual interest convergence will provide only an approximate fixation on corresponding points. Such loose convergence is insufficient when a stronger interest calls for a sharper impression. The internal recti (the ocular muscles concerned with convergence) then refine their efforts to meet this demand. This refined reflex which gives perfect fusion—highly detailed single vision—occurs only when a maximal degree of spontaneous or *involuntary* attention is present. In any case the quality of reflex is nicely adjusted to psychic demand. The eyes furnish as much definition as the mind requires, and no more.[136]

It is not to be inferred, however, that any degree of voluntary control intervenes with heightened demand. The reflexes remain reflexes; they merely become keener ones. The cortical basis of this influence is not known. If the more vivid quality of awareness called attention is the result of more intensive or vigorous cerebral functioning, the sharpening of reflex activity may be supposed in some way to result from such an accelerated neural tempo. The point to be emphasized is that the sharpened muscular coordinations are as completely self-governing at the higher levels of psychic demand as at the lower. Attentive consciousness focusses more acutely as interest rises in pitch, but it is still centered upon the *sensory impression*. It does not expand to embrace any conscious control of ocular adjustments. It is absorbed with the afferent process, so to speak; the efferent is now, as always, involuntary. This statement implies, of course, no denial of the fact that exploratory ocular fixations are almost as much under voluntary control as are exploratory movements of the hands. Simply, the more subtle grades of adjustment involved in precise fusion and focus take place when the mind is filled with the image itself, and with the desire for further refinement of the image. Fulfillment of this desire achieves itself automatically. While demand may on occasion be intentionally "stepped up," it is reported that the keenest reflex is obtained only when interest is spontaneous and real, as well as strong.

One more point may be enforced in this connection; namely, that the psychic condition for high reflex obtains only when

interest is directed to the stimulus-object itself; only when it centers upon the sensory impression, that is, rather than upon its possible mental associates or meanings. This can be illustrated in the development of reading ability. Printed words, when the child first encounters them, are unfamiliar visual patterns. As with any other unfamiliar object, they must be closely scrutinized to be identified. *All* of the "sign" is needed to evoke the response. At this stage a relatively high reflex is consequently required. As familiarity with the more common words of the language grows, a less distinct visual impression is sufficient to touch off recognition and the arousal of meaning. Simultaneously attention begins to shift to meanings, since these, after all, are the goal of the reading process. Gradually diminishing demand for precise image definition, releasing interest for the task of comprehension, is accompanied by a corresponding gradual relaxation of the reflexes. The eyes move more rapidly over the line; a glance at the general form of a word suffices; perfect fusion and sharp focus are not required for the production of such sketchy, blurred, but adequate outlines. The main interest has now withdrawn altogether from the signs and become fixed on the narrative of the story or on a grasp of the significance of the statements of the writer. At this stage whole phrases are taken in at once; misspellings are overlooked, and only a small fraction of the original stimulus is needed, the amount varying considerably with the individual.

Any interference with this rapid and smooth-running operation of partial stimuli, e.g., an illegible or unfamiliar word, a Latin phrase, will cause attention to instantly revert to the image and entail a pause in the procession of meanings. Simultaneously the level of reflex function will rise until the stimulus difficulty has been disposed of. It will be seen from the foregoing that a test of visual acuity must likewise be designed to arouse as great a degree as possible of spontaneous interest in the test target itself. It has been suggested that the familiar letters of the standard Snellen chart are not well adapted to his end. The ideal target figure would excite, at least for a few moments, a genuine interest in the figure itself, apart from the ulterior concern with the purpose of the examination. Any such device, on the other hand, should make its appeal *directly*

and not through its associated meanings, since it has been noted that the withdrawal of interest from the fixated object immediately lowers the quality of reflex coordination.

## SUPPRESSED VISION

A few paragraphs may be added here on the psychology of suppression as a further instance of the part played by attention in the sphere of vision. The intention is merely to attempt a descriptive phrasing of the development of suppression as a visual attention habit, and to indicate a few parallels in an adjacent sensory field.

Among the psychological disorders of vision, suppression amblyopia, or amblyopia ex anopsia, is perhaps the most common. It has been defined as a partial or complete loss of vision, affecting the macular region only, which is functional in character, i.e., in which there is no discernible structural change in the ocular tissues which might be the cause of the visual loss. It is the result of a suppression or exclusion from consciousness of one of the two images.

In the majority of cases the suppression develops on the basis of such difficulties as a bad astigmatism in one eye, a marked difference in visual acuity between the two eyes, or neuromuscular troubles which make accurate binocular fixation either an effort or an impossibility. In the latter case, where fusion of the images is difficult, the individual obtains single vision simply by disregarding one of them. In a case of convergent strabismus (cross-eyes) the image of a fixated object falls on the macular area of one eye and upon an extra-macular area of the other, i.e., upon non-corresponding areas. The result of this is diplopia, or double vision, which can be abolished only by suppression of the unwanted image from consciousness so long as the strabismus remains. Where a fusion trouble is present and binocular fixation imposes a strain, the resort to suppression might be compared to the situation of a manual worker who finds his performance easier when he uses one hand than when he attempts to coordinate both. He settles into a habit of one-handed manipulation. The monocular visual habit would logically be expected to develop more readily in individuals in whom binocular vision is not firmly established. Correspondingly, the defect more often develops during childhood than after maturity.

When the vision of one eye is considerably superior to that of the other, attention tends to be drawn away from the poorer image and toward the better one; psychic demand, in other words, will be made upon the more informative of the two images. The individual ceases to "look" through both eyes equally, so to speak, because he can see so much better with one eye. When, for example, the visual impression obtained with the right eye alone is found to be just as satisfactory as the binocular image, but far superior to the impression obtained with the left eye alone, the binocular image may obviously be regarded as primarily a monocular product. A monocular visual *attention habit* may develop on this basis which will later exclude the left image from consciousness even after it has been greatly improved by a lens.

Suppressed vision may therefore be interpreted in terms of the psychology of habit formation, the essential principle of which is that the repeated exercise of a reaction renders it more facile and strengthens the tendency to use it. Now, the process of attending to a stimulus, the focussing of consciousness upon it, is a mental activity, or form of reaction, and in this connection the significant fact is that the repeated directing or focussing of attention upon a particular source of stimulation may cause a corresponding habit to be formed, whereby selected stimuli constantly predominate in consciousness to the partial or complete exclusion of others simultaneously active upon the sense organs. The monocular visual habit of a microscopist or a watch-maker, for example, whose trained attention bars from consciousness for long periods the image of the unused eye, is an example of this.

Illustrations of selective attention are perhaps more numerous in the domain of hearing. That of the office worker who has learned to suppress the sounds of voices, clattering typewriters, etc., while he hears distinctly the relatively much fainter sounds from the 'phone receiver, is a familiar one. In a similar fashion one can select the sounds of a single instrument out of an orchestra and place it, attentively, in the foreground of one's impression of the complex whole.

Such habits of selective sensory attention are more strikingly seen among neurotics. Here the phenomenon has passed beyond voluntary control—a condition which any strong habit may ap-

proach. Cases are reported of functional deafness following upon organic deafness which appear to be closely related to similar disorders of vision. The patient remains deaf even though the original organic cause of his deafness has been removed, because his attention, during the period of actual deafness, has been habitually focussed upon his remaining senses and has finally become crystallized in this form. He has formed a *habit* of *not listening*, fixed, rather than controllable at will, as with the above-mentioned office worker. One is reminded here of the child who manifests amblyopia after a period of wearing a bandage over an injured eye.

The opposite disorder of attention was observed during the war in soldiers who were constantly and despite themselves "straining their ears" for the warning sounds of approaching shells, even when many miles away from the zone of action. The possibility of an underlying neurotic constitution in some of these cases does not affect the fact which they illustrate, namely, that selective attention may become fixed as a form of reaction, either as a heightened state of activity, or in a way which excludes, to various degrees, the impressions of one of the sensory channels. When the image suppression which affords an escape from double vision or from a fusion strain becomes too strong to be voluntarily set aside, special means are needed to remove the barrier, to break the habit of inattention.

This interpretation is strengthened by the fact that it is the macular area alone which is affected in this type of amblyopia. The extra-macular area is superior to the macular in reactivity to all forms of visual stimulation. Colors diminish in saturation as they approach the macula, *i e.* the center of the visual field, when moved inward from the intermediate zone. The form sense here, likewise, can be shown by perimetry to be inferior to that in the intermediate area. In congenital amblyopia there is brightness constancy as between the two zones, while in suppression a fixated target appears of lesser brightness than one seen indirectly. The significance of these facts regarding the suppression form of the defect is apparent when we remember that it is the macula that corresponds to the field of *attentive* visual consciousness, and that therefore an habituated suppression of attention would be expected to express in a loss of central vision only. Since, normally, we are not

attentively conscious of extra-macular images, these are not affected by the suppression process.

The nature of the treatment for suppression bears out its interpretation as psychological in character. The monocular attention habit must be broken and "equally attentive vision as between the two eyes" awakened. Training in fusion must wait until the suppression barrier has been removed and consciousness again becomes receptive to both images. The logic of "flash stimulation" with bright colors for the amblyopic eye, and of exercises with the amblyoscope in which the stimulus for the defective eye is highly illuminated, follows clearly from the premise that a restoration of attention is the primary aim.

## Chapter VII

# VISUAL SENSATIONS

Visual sensations were defined earlier as conscious experiences which can be directly attributed to sense organ activity. For the sake of simplicity we may regard all perceptual experience as having two sources: the data supplied by the senses at the present moment, and the data supplied by memory, deriving from the past. Each moment of visual experience, typically, draws upon both of these sources. The retina gives certain impressions which are instantly overlaid by the memory residues of previous impressions, visual consciousness in its perceptual form consisting of a fusion of the data coming from the eye, on one hand, and the "mind" on the other. When, as was pointed out in Chapter IV, a content of consciousness is discovered which could not, by its nature or by consideration of the character of retinal stimulation, be furnished by the eye, it must represent an expression of the processes of associative memory.

When, however, it is possible to account for such contents as the direct results of the functioning of the receptors, when, that is, one is aware of a fact or quality of an object in immediate consequence of its stimulation of a sense organ, the contents are referred to as sensations. Thus a new born infant may be assumed to be conscious of differences in the size, form, color and motion of objects; these data are sensory, since the character of retinal stimulation alone is adequate to account for them. The only qualification needed in connection with this statement follows from the fact that there appear to be fundamental traits of experience, in class with sensation, which express interactive processes in the visual nervous system at a higher level than the receptor. These features were indicated in the discussion of visual "gestalts." In view of these facts the physiological basis of sensory experience may be extended to include

certain primary processes in the visual cortex as well as those of the retina. For most of the purposes of the present chapter, however, sensory experience may be regarded simply as the first conscious response following retinal stimulation, "pure" of the influence of past experience in the sense in which this term has previously been used.

The study of sensations, accordingly, center upon the stimulation, the receptor, and conscious responses of the "first order." This means, in the case of vision, that discussion will be concerned with light, the retina, and the resultant qualities of sensory consciousness. At the present place the qualities referred to will include the color, brightness, and saturation of sensory impressions.

It is implied in the last statement that light and the responses it evokes are two different things. While the distinction is fairly obvious it is universally belied in ordinary discourse and in popular thinking. Thus a student may one moment define a color as the psychological consequence of a certain kind of retinal stimulation, and the next moment, unaware of any contradiction, refer to grass as "green" as though the greenness were actually resident in the grass. While the distinction between stimulus and color experience is doubtless a wholly pointless one from any "practical" viewpoint, it may deserve at least a brief mention at this place as an item of modern doctrine.

In summary, the "color of objects" is projected upon them and does not exist as a part of them. The physical object is to be regarded as a colorless mass of particles,—electrons, protons, etc., whose motion sets up vibrations, also colorless, in a hypothetical medium filling all space. The neural impulses resulting from the action of this radiant energy upon the retina are also conceived as colorless. Only when these impulses pass through the cells of the visual cortex does "color" come into existence, and then solely as an *experience*, since the impression of color is not to be identified with the neural activity itself. Color sensations, then, are psychological facts, and the term cannot be accurately applied to either the physical or the physiological energies and processes which are antecedent to its production. It would therefore be possible to set forth a purely descriptive account of color experience without reference to these antece-

dents, any discussion of visual sensations, to be satisfying, requires some statement as to the correlated stimuli and structures.

## PROPERTIES OF VISUAL SENSATIONS

**Brightness.** A fundamental division in the study of visual sensory experience is that between color, or chromatic, sensations, and colorless, or achromatic, sensations. The latter include white, black, and the intermediate greys, which may be regarded as blends of white and black. A series of papers ranging from pure white through many greys progressively darker in shade and ending in jet black is called a *brightness series*. The different papers may also be said to differ in luminosity or brilliance. The meaning of brightness and of differences in brightness is best illustrated in such a series. The brightness of a particular color may be most simply defined in terms of the shade of grey with which it can best be matched. Pink, for example, matches a shade of grey much lighter than the grey which will match red. Pink, accordingly, is a lighter or brighter shade of red; by the same token blue is a darker color than yellow. In observing the colors of the spectrum it will be noticed that the region of yellow is brightest, and that there is a decline of this property in either direction from the yellow.

**Saturation.** Various facts about color may be demonstrated by placing circular pieces of colored paper on an electrically

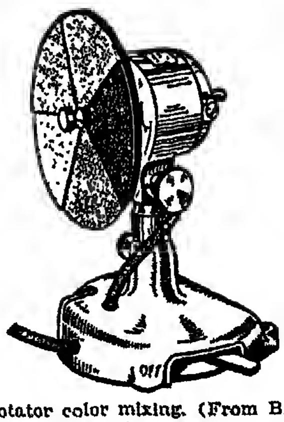


*Fig. 36.* Rotation rotator color mixing. (From Bills, General Experimental Psychology, Longmans, Green & Co.)

rotated disc (Fig. 36). If one-half of the surface of the disc is covered with red paper, the other half with yellow, and the

disc is then rapidly rotated, an orange blend of the two colors will result. If grey be substituted for the yellow the resulting color will still be red, but of a different quality than that of the original red paper. It will be a shallow, pale, greyish red. If the grey chosen was one which matched the red for shade, the red resulting from fusion will be no brighter and no darker than the original, *i. e.* there will be no change in *brightness*, but there will be a dulling of quality which is called a loss of *saturation*. Saturated colors are rich and full bodied; pink and pale blue, for example, are shallow and unsaturated.

The larger the amount of grey added to the disc in the above illustration, the lower the saturation of the red, until finally it would disappear entirely. If a grey lighter than the red in shade is chosen, the blend will again show a loss in saturation but the red has now gained in brightness; it is lighter as well as duller. By adding a dark grey—darker in shade than the grey which matches the red, a darkened red will appear in the blend. The red has now been reduced in brightness as well as in saturation. Saturation, as Troland suggests[188], is a measure of the *amount* of a color. Necessarily, the more white or grey is mixed with a color, the less of its essential quality will remain.

**Hue.** A third property of visual sensation is hue, or, in the common sense, color itself. A blue and green, equal in both saturation and brightness, differ in hue. The term applies also to a mixture of colors, such as bluish green. The colorless sensations are usually regarded as forming a linear series between white and black. The established "arrangement" for colors is based upon their distribution in the spectrum. Here, from left to right, the colors are red, orange, yellow, yellow-green, green, blue-green, blue and violet. Four of these: red, yellow, green, and blue, are called the *primary* colors. The others, as the terms yellow-green and blue-green suggest, appear to be blends of the primary colors. Orange, for example, might be called a red-yellow. Any of these blends may be obtained by mixing the proper pairs of primaries on the color disc, as described previously. In order to obtain violet, however, it would be necessary to mix a little red with a large amount of blue. Adding more red would result in a series of colors which are not found in the spectrum, namely, the purples, or blue-reds. The pro-

gressive addition of red to the mixture would eventually lead back to the original red with which the list began. The color series is thus a circular one.

The fundamental or primary colors stand out in the spectrum as having a distinctive quality of elementariness. They appear to be pure and irreducible, "unique and unmixed." A blue-green, for example, may exhibit both hues in equally pronounced quality; similarly yellow and green are both discernible in "olive." The blends unquestionably bear a resemblance to certain primary colors. But this quality of resemblance is not present in the primary colors. Neither blue nor green suggest blue-green in the way that blue-green suggests both blue and green. And there is a greater resemblance between red and orange, and between orange and yellow, than there is between red and yellow. The primaries have a purity of essential hue which distinguishes them from the blends.

Some authorities[180] maintain that while such a blend as orange, for example, does resemble red and yellow, it does not actually exhibit either red or yellow as such—that orange *is* a specific hue in its own right, in which neither primary is really seen. It may be preferable to state simply that some colors are more *outstanding* than others when all are arranged in order, in the same sense that white and black stand out from the greys in the brightness series. However defined, the distinction between blends and primaries is a basic one, and color classification is much simplified by regarding the blends as compound colors whose elements are the four primaries.

Figure 37 is a diagrammatic symbol of the relationships of hue, brightness and saturation. The brightness series, which is linear, is represented by the central vertical line between white and black. The hues, which are a circular series, as previously explained, are represented on the circumference of the cylinder. The blends would be represented by points on the circumference between the four primaries. A fully saturated color, whatever its hue, would be placed *on* the circumference, while a less sat-saturated color would be placed somewhere on a radius between the circumference and the central axis of the cylinder. The less its saturation the closer it will lie to the center of the circle, representing grey or the zero point of saturation. All of the points within the plane of the middle circle will represent colors

differing in hue and in saturation. Differences in brightness will be represented by points above and below this plane, measured by the vertical distance of the point from white or from black. A visual sensation of any hue, brightness and saturation would thus find its place somewhere in the space enclosed by the

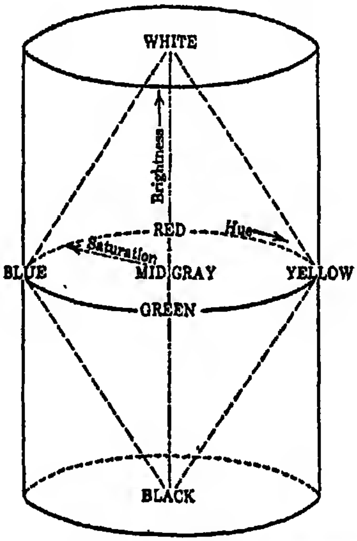


*Fig. 37.* Diagram symbolizing the relationships between color, brightness and saturation. (Reprinted by permission from "Psychology" by Boring, Langfeld and Weld, published by John Wiley & Sons, Inc.)

cylinder. The broken lines representing a double cone within the cylinder, symbolize the fact that saturation diminishes as brightness is raised or lowered in relation to the intermediate brightness indicated by the "mid-grey" point. The most saturated colors, that is, are about midway in the brightness scale.

## STIMULUS AND SENSATION

Light may be defined as that form of radiant energy to which the visual sensory system responds by arousing sensations. This energy may be thought of, physically, as propagated as a wave motion of the particles of a hypothetical ether. The first statement implies that there are forms of such energy to which the eye does not respond. As a matter of fact the eye is sensitive to a very restricted range of radiant energies; those, namely, whose wave lengths (measured from crest to crest) fall between 760

millimicrons (millionths of a millimeter) and 390 millimicrons. The former wave lengths correspond to the red end of the spectrum, the latter to the violet end. Wave lengths longer than those of the red do not affect the eye; heat waves and radio waves are among them. The eye is likewise insensitive to waves shorter than the violet—the X-rays, for example, and those that tan the skin in the summer. All of these energies are forms of wave motion differing only in length, but the eye is so constituted as to respond to a certain range of these and not to others. The term "light," therefore, is applied to this range.

Differences in hue are the result of stimulation by different wave lengths of radiant energy. There is a continuous scale of minute changes in wave length between the limits given above but the eye does not respond differently to all of these slight differences. Instead it responds to a limited number of sections of this scale to provide a relatively small number of more or less uniform primary hues separated by transitional colors; these are the hues listed previously. Hues, therefore, are a function of wave length, and it is possible, by filtering out of white light —with a colored glass, for example—all wave lengths but one, to arouse any desired hue experience. When all light waves stimulate the retina together the sensation produced is that of white or grey.

Figure 38 represents (a) the colors as a circular series of blends and primaries, and (b) the wave lengths of the primary spectral colors in millimicrons, with the approximate wave length

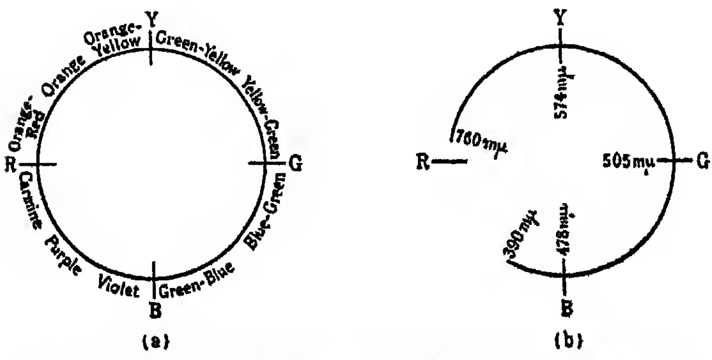


*Fig. 38.* The psychological color circle. (Reprinted by permission from "Psychology" by Boring, Langfeld and Weld, published by John Wiley & Sons, Inc.)

ranges corresponding to the intermediate colors. The gap in the circumference of (b) symbolizes the fact that the carmines and purples of the psychological color circle (a) do not occur in the spectrum. These hues are not produced by a single wave length or a restricted range of wave lengths, as are the spectral colors; they require a mixture of long and short waves.

Seldom does a light source send waves of a single length to the eye. Typically the light reflected by common objects is a mixture, in which, however, certain wave lengths predominate to give the object its characteristic hue. The saturation of a color is determined by the *purity* of its stimulus—the freedom of its wave length from mixture with waves of other lengths. Since white or grey light contains all wave lengths the easiest way to reduce the saturation of a hue—to diminish its purity, is to mix it with grey, as was indicated in the earlier description of changes in saturation. But a more restricted mixture achieves the same result; the saturation of a mixture of two colors, for example, is lower than that of either component. The hues of the spectrum exhibit very high saturation, although it is possible, by means to be described later, to obtain hue impressions even richer than these.

The brightness of visual sensations is primarily a function of the *energy* or intensity of stimulation. Intensity may be thought of schematically in terms of the amplitude of wave motion[140] (from crest to base of the wave), or, more dynamically, as proportional to the rate of propagation of radiant energy upon the retina.[141] Generally, as the intensity of radiation increases, the experience of brightness or luminosity also increases. The physiological basis of such changes was discussed in Chapter II. Brightness, however, is not solely a function of stimulus intensity. The above-stated relation holds only for stimulation whose wave length composition is constant. The varying brightnesses of the different parts of the spectrum are not determined by differences in the physical intensities of the various corresponding wave lengths. This variation in brightness is partly the result of unequal sensitivity of the retina itself to the different wave lengths. The brightest portion of the spectrum is in the region of the yellow; in ordinary daylight illumination the retina is most sensitive to ether waves in the neighborhood of 550 millimicrons; its sensitivity

declines steadily toward the longer and shorter sides of the wave length scale. The brightness of visual sensations is therefore conditioned by a physiological as well as a physical factor.

The factors of duration and intensity of stimulation also have relations to the experience of color. Light must act for a certain minimal time in order to arouse color impressions; an interval of stimulation shorter than this will produce a sensation of colorless luminosity only. The same statements hold in relation to the intensity of stimulation, which must also reach a certain minimum to produce a chromatic response. Very long exposures to stimulation, on the other hand, will weaken the quality of color; prolonged fixation on a colored surface tends to reduce its saturation. The intensity of stimulation likewise affects color quality. Saturation is low at very weak and at very great intensities. With sufficiently intense stimulation saturation falls to zero and only luminosity remains.

## RETINAL FACTORS

As previously indicated in regard to brightness, the character of visual sensations cannot always be accounted for in terms of stimulus factors alone. There is no simple system of "one to one" correspondences between stimulus and psychological response. The relationships between intensity, wave length, and purity of the stimulus, on one hand, and brightness, hue and saturation, on the other, may be markedly modified by certain variables in the functioning of the retina itself. Some of the phenomena expressing the effects of such variables may now be introduced.

**Adaptation to Darkness.** As we pass from the glaring sunlight of noonday into the darkness of a theatre we may be unable to move with any certainty for several minutes; the rows of seats and spectators are cloaked in an impenetrable gloom. Gradually, however, objects take shape, and finally we become aware of what by contrast with the first impression appears to be a surprisingly high degree of illumination. The amount of light in the visual field has, of course, been constant during this change, but the retinas have become progressively more and more sensitive until they respond to quantities of light radiation which were at first without effect. With no change in retinal stimulation there has been a change in visual experience. The student will recognize here one more in-

stance of the failure of these two to "check." A number of such instances were considered under the heading of Visual Perception and attributed to the supplementation of present impressions by the memories of past experience. In the above case, however, it is to the receptor rather than to the mind that the lack of correspondence between stimulation and consciousness is to be charged. Variations in the functional capacities of the sense organs offer a new factor in this relationship. The brightness of visual sensations depends, therefore, not only on the intensity and wave length of the stimulus, but on the level of retinal sensitivity, which in the case of dark-adaptation may increase several thousand times with a sufficient interval.

The rise in retinal sensitivity during adaptation to darkness occurs gradually over a period of about half an hour. Marked individual variations in the rapidity and amount of increase in sensitivity are observed. Some people see much better in low illumination than others. In a few people the rise may be extremely slow, though the ultimate sensitivity is near normal. Occasionally there is very little increase after several hours, and such cases are known as "night-blind," a defect which is sometimes hereditary. It may also be due to diseases of the eye.

The twilight increase in retinal sensitivity is not, however, equal for all portions of the retina. That of the macular area changes relatively little as compared with the periphery. In daylight the macular area is the most light-sensitive part of the retina; sensitivity is rapidly reduced with distance from the center, being only one-fortieth as great for color at a distance of 35°. In twilight, however, the macular zone is the least sensitive part of the retina. Astronomers discovered many years ago that stars of small magnitude could be seen better if viewed with indirect vision. The feebler the light the more eccentric the fixation which gives best vision, sensitivity therefore increasing with distance from the center, up to certain limits.

**The Purkinje Effect.** In daylight illumination the yellow region of the spectrum is brightest, luminosity, as stated earlier, being partly determined by the differential sensitivity of the retina to different wave lengths. If the spectral series is viewed by very low illumination it is found that a shift of the region of highest brightness occurs. This shift is in the direction of

the short wave end of the spectrum, and it is found that the green is now the zone of maximum luminosity. Yellow and red become duller and are first to disappear as the light is reduced; the relative visibility of green and blue is raised, and they remain visible after the others have disappeared. Blue and red papers which appear of equal brightness in daylight may be used to demonstrate this effect. With low lighting the blue will be observed to become noticeably brighter than the red. In the daylight spectrum red is several times brighter than blue; in twilight vision blue becomes many times brighter than red. It is clear that inasmuch as intensity in these instances is uniformly reduced for all wave lengths of light, the change in brightness values must be an expression of changes in retinal sensitivity. The eye, under twilight conditions, has somehow become more responsive to the short waves of blue and green, and less responsive to the long waves of red and yellow. The Purkinje shift is a phenomenon of peripheral vision only. If test colors small enough to fall within the limits of macular vision are used, and care is taken to maintain direct fixation, the change in relative brightness of the long and short wave colors is not observed. The phenomenon is slight in amount, if present at all, in cases of night-blindness.

Color Vision and Retinal Area. Sensations of hue and saturation are a function not only of the wave length and intensity of stimulation but of the retinal area affected as well. If, with the eye motionless, a colored object is moved out from the center of the field a steady decline in its saturation will be observed. A point in the periphery will be reached at which the object, while still visible, has become colorless. The peripheral region of the retina is color blind for stimuli of moderate intensities. The point at which color vanishes, however, will depend partly upon the initial color quality of the stimulus; if its saturation is high its hue will be sensible at a greater distance from the central field than will that of a less saturated color. Brightness of illumination, the size of the test colors, fatigue, are other factors which markedly affect the limits of the color fields.

Some colors exhibit only a progressive loss of saturation as they are moved away from the central field. Most colors, however, show a change of hue as well. Green and red, for

example, become yellowish before turning grey. Colors of which red is a component, such as orange and purple, lose this quality first as saturation is reduced, becoming yellow and blue, respectively. Red and green components disappear first; yellow and blue persist longer. Clearly, a retinal variable must underlie these changes in visual experience, since physical stimulation does not change, except in the location of its source. Such variations in hue and saturation are, like double images, seldom noticed, since the images of objects viewed are normally fixed on the macula, where color quality is constant; attention, moreover, is usually directed to the same point, and we rarely have occasion for attempting observation of objects indirectly seen.

## RETINAL STRUCTURES AND FUNCTIONS

The light-sensitive portion of the human eye consists, essentially, of two different kinds of receptor cells, the *rods* and *cones* (Figure 39), so called because of their form. The retina

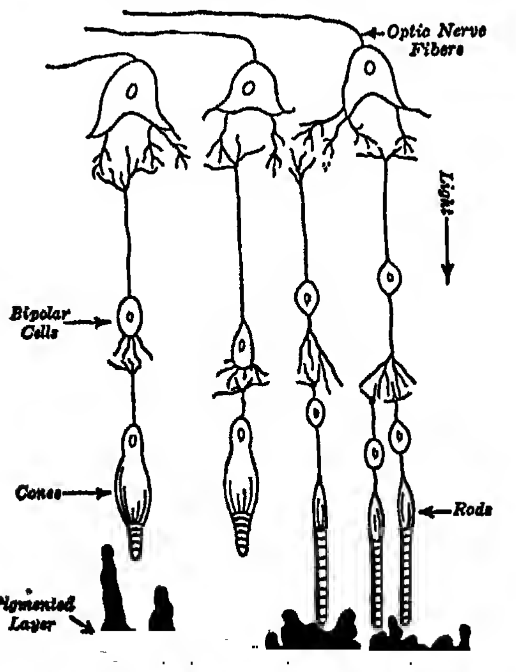


FIG. 39. The rods and cones of the retina. (From Gates, Elementary Psychology, The Macmillan Co.)

contains millions of these structures. The overlying cellular layers, as the figure shows, consist primarily of the neurons composing part of the afferent paths to the brain. Light must pass through these layers in order to affect the receptor cells; the nerve impulses therefore must pass in a direction opposite to that of the entering light during a part of their course out of the eye. At a small area of the retina called the *fovea,* directly behind the pupil, all of the accessory cellular layers are moved to one side, exposing the light-sensitive cells to the direct action of the stimulus. This absence of any obstruction, together with the fact that the cones here are extremely numerous and very closely packed, and that each has its individual afferent path, point to the fovea as that part of the retina specialized for the greatest sensitiveness and refinement in the recording of the image. Surrounding the fovea is the macula; this central area as a whole contains only cones.

From the center of the retina outward to the periphery there is a steady diminution in the number of cones and a continuous increase in the number of rods until, at the vertical equator of the eye, there are three times as many rods as cones[142], though the cones extend out as far as the peripheral limits of the retina. By referring to the cones and rods as the "light-sensitive elements" of the retina, it is meant that changes, probably chemical in nature, are produced by the action of light upon these structures, in a manner comparable to that by which light images effect changes on a photographic film. It is known that the rods contain a substance, called *visual purple,* which is chemically changed by the action of light; it bleaches when exposed and regenerates in darkness. It may be assumed that the cones also contain a similar substance, and that the chemical processes set going by the absorption of the physical energy of light eventually lead to the arousal of nerve impulses.

**The Duplicity Theory.** Structural differences suggest differences in function, and the theory that the rods and cones subserve two more or less distinct purposes is well established. A relationship is clearly suggested between the visual phenomena described previously and the fact that the central retinal regions are populated predominantly by cones, the peripheral regions by rods. The relatively much higher sensitivity of the extra-macular areas in low illumination; the weak-

ness or absence of color vision in the periphery; the fact that the Purkinje shift in brightness is an affair of extra-macular vision, involving the areas containing *both* rods and cones; the fact that the saturation of colors is highest at the center of the visual field, all suggest that the rods are the primary receptors in twilight vision, furnishing brightness sensations only, while color vision is an expression of the activities of the cones.

Other observations support this view. Certain animals, for example, have a great predominance of rods in the retina, others a predominance of cones. The former are nocturnal in habits, like bats, owls and mice; the latter have good day vision and are night-blind, e.g., birds. The rods, it seems clear, are the receptors for low intensity vision (scotopic), while the cones are the chief receptors for vision at normal and high intensities (photopic). The two kinds of receptors differ in their reactive capacity for different wave lengths, the rods being most sensitive to green, the cones to yellow. The Purkinje shift represents the transition from cone vision to rod vision and can occur, therefore, only where both rods and cones are present, outside the central zone.

The color blindness of the retinal periphery, according to the duplicity doctrine, results from the absence or near-absence of cones in this area. The color changes observed when objects are moved from center to periphery occur in full daylight illumination (i.e., in cone vision), however. The loss of saturation may be related to the reduced number of cones as the periphery is approached. The hue changes will be referred to later in the discussion of color theory.

## THE MIXTURE OF COLORS

It was stated that hue is determined by the wave length of the light stimulus, but here again there is no constant one-to-one relation between stimulation and mental response. A given hue may be elicited by a particular wave length, and it may also be obtained by a proper *mixture* of wave lengths. Orange, for example, results from retinal stimulation by a wave length of 650 millimicrons; it also results from a combination stimulus of 700 and 600 millimicrons, the latter being the stimuli for red and yellow, respectively. Other secondary colors, such as olive (yellow-green) and blue-green, may be similarly obtained

by a single wave length, or by a mixture of two. The exception to this is purple, which is obtained only by a mixture and is not, therefore, found in the spectrum.

Hue experiences may be compounded in several ways. Physical lights of different wave lengths may be directly mixed and projected upon the retina simultaneously; or the retinal processes corresponding to different color experiences may be "mixed" to give the same results. The latter method is a simple one and involves a rotating surface (Figure 36) on which colored papers are placed. By rotating a half-disc of red, for example, with a half-disc of yellow, it is possible to arouse the retinal processes for these colors simultaneously, the retina being stimulated by the two wave lengths in such rapid succession as to give the same effects as would be obtained by mixing the physical lights themselves. That is, the retinal processes for one color remain active for an interval *after* the arrival of the stimulus for the adjacent color on the disc; since the physiological bases of the two color experiences are simultaneously present, the experiences themselves are fused. By this means the entire series of hues, saturations and brightnesses may be obtained by the mixture, in various proportions, of one hue with another, of a hue with greys, lighter and darker, etc. A brightness series for any hue would be obtained by mixing it with various shades of grey. All kinds of blends may be obtained by varying the relative amounts of surface for each color exposed on the disc. The greater this amount, the longer the corresponding light will be active on the retina, and the greater the subjective prominence of this component in the color experience. Differences in the brightness of the hues blended will similarly affect the quality of the blend.

A striking feature of color mixing is that while certain hues blend to give other hues, there are pairs of colors whose mixture results in no color at all. Such pairs are called *complements.* Yellow and blue, red and bluish green, green and bluish red (purple), are examples of such pairs. Mixture of these pairs in the proper proportions gives grey; in other proportions the consequence is *either* one color or the other in reduced saturation—never an intermediate hue in which both components are distinguishable. This holds true of all complementary pairs, and the formulation is one of the "laws of color

mixture." A second law applies to the mixing of non-complementary colors, and states simply that intermediate hues result from such mixtures, and that the quality of these intermediates is determined by the relative proportions of the component colors. With the exception of purples these intermediates will be located in the spectrum between their component hues. The saturation is usually less than that of the spectral color, however, and less than that of either component. A peculiar case is that of red and green. These hues are not complementary; neither do they blend. When mixed in the right proportions both colors disappear and *yellow emerges,* low in saturation. The point has a special significance for color theory, as will later be seen.

Students acquainted with the rules of the mixture of pigments are frequently confused by the different results obtained by the method described above. This method amounts to a simple addition of the physical stimulus or of the retinal process for one color to that for another color. The color of a pigment is the result of the selective absorption of light. The chemical composition of blue paint, for example, is such that it absorbs nearly all wave lengths of light except those whose reflection to the eye gives the sensation of blue. The same is true for yellow paint. When the two are mixed their combined *subtractive* or absorptive powers result in the reflection of the wave lengths for green to the eye. The process may be illustrated with pigmented glass. White light passing through a yellow glass placed next to a blue glass issues forth from the two media as green. The blue glass actually transmits some green along with its blue light, the yellow glass some green with its yellow. Placed together the blue glass absorbs all but blue and green from the white light; the blue light is next absorbed by the yellow glass, with the result that only the green passes through to stimulate the eye.[148]

## COLOR CONTRAST

**Simultaneous Contrast.** There are several forms of contrast phenomena, some observable in other sensory fields as well as in that of vision. Those of *simultaneous* contrast are probably peculiar to the visual sense. They are manifested in relation to brightness, hue and saturation. These effects are of special interest as showing that the response made to a visual stimulus

is determined not only by that stimulus but by adjacent visual stimuli as well. The sensation mediated by a given area of retinal stimulation *may be strongly influenced by activities in* adjacent retinal areas. There are processes of *interaction* between such parts which often have rather striking expressions in visual consciousness. If a piece of grey paper, for example, is placed upon a ground of blue paper, it will appear tinted with yellow at its margins. On a green ground it will appear slightly purplish, the effect being most marked at the boundary. Any color may be induced on the grey area by surrounding it with a color complementary to the one desired.

If, however, a piece of colored paper is placed on a ground complementary in hue, each will deepen the saturation of the other, the effect again being most marked at the boundaries and diminishing with the distance from them. The hue of a small square of yellow paper placed on a larger sheet of saturated blue will be strikingly raised in richness in comparison with its observed quality in the absence of such surroundings. The effect may be regarded as the reinforcement of a hue through induction of the same color by its adjacent complement. The blue, that is, will induce yellow in an adjacent grey; if a yellow paper is substituted for the grey, the induced yellow contrast effect will simply strengthen the quality of the yellow already present. Corresponding results are obtained with non-complementary pairs. If red is placed adjacent to blue, the induced yellow effect of the blue will incline the red toward orange; the induced bluish green effect of the red (red and bluish green being complementary) will give a greenish tinge to the blue. Saturation may be reduced as well as raised by contrast. If a blue low in saturation is placed on a blue ground of high saturation, the former will be still further reduced. The effect may be regarded as the result of the induction of the complementary hue by the surrounding color—the induced yellow superposed on blue tending toward grey.

Luckiesh[144] demonstrated these phenomena interestingly by means of a simple device designed for the observation of adjacent surfaces variously illuminated. A box (Figure 40) is partitioned into two compartments with an aperture at "H", the latter in the form of a small star. The screen (of white

blotting paper) at "C" is seen through this aperture by the observer at the right. The screen is illuminated by the lights at "R", with any hue and intensity desired. From the position of the observer the illuminated star-shaped area of the

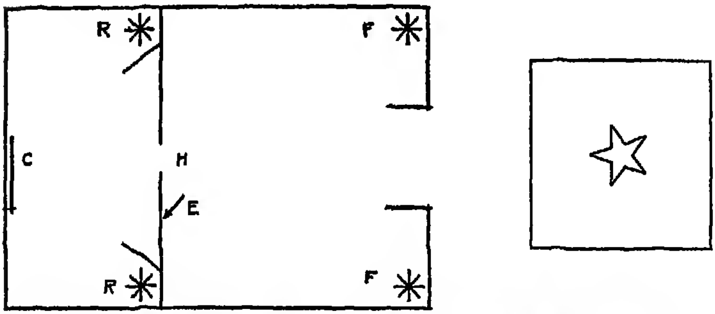


*Fig. 40.* Apparatus used by Luckiesh to demonstrate contrast phenomena. (From Luckiesh, Visual Illusions and Their Applications, D. Van Nostrand Co.)

screen (illustrated by the figure on the right) is seen against a ground or "environment" furnished by the partition at "E." The latter may be variously illuminated by the lights at "F." In effect, a star of any color may be viewed against a ground of any color.

Simple complementary contrast effects were illustrated. In a green, red, or yellow environment the white-illuminated star (screen "C") was tinted with purple, bluish green or blue, respectively. Reinforcement effects were also easily produced. An orange or yellow star surrounded by blue, for example, became more vividly orange. A purple star of low saturation (greyish) became richly purple when surrounded by bright green. When the same weakly purple star was surrounded by a rich purple ground, however, it became greenish, the green contrast effect of the purple ground being strong enough to overcome the "real" purple of the star. Hue experiences may thus be induced in the absence of the corresponding wave length, or, once present, may be raised in saturation, solely by the effect of contiguous stimulation, as a kind of by-product of such stimulation.

Adjacent colorless surfaces also exhibit contrast effects. Two identical pieces of grey paper, one placed on a white ground,

the other on black, appear quite unequal in brightness (Figure 41). This effect is reciprocal; at the boundary between white and black papers the white is whiter, the black is blacker, the effect diminishing in degree with distance from the line of

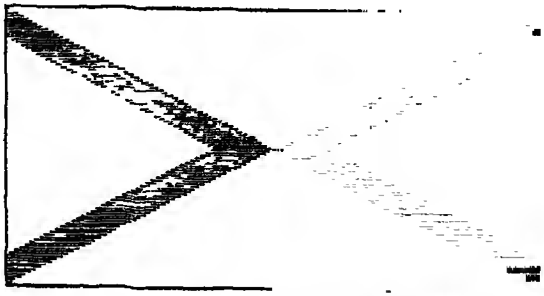

*Fig. 41.* Brightness contrast. (From Luckiesh, Visual Illusions and Their Applications, D. Van Nostrand Co.)

juncture. Contrast effects comparable to those described with regard to hue may also be obtained. Thus a grey which appears white by comparison with a dark ground may be made to appear almost black if the ground is changed to an intensely bright one. Many automobile drivers have observed that the gloom of the night is deepest just beyond the area illuminated by the headlights. It is said that stage properties may be changed in full view of the audience by workmen at the wings, whose movements are hidden by the darkness generated by contrast with the brightly illuminated center of the stage. The brightness of colors may likewise be raised by contrast with surroundings. Two squares of blue paper, one on a black ground, the other on white, will appear unequal in brilliance on comparison. There are numerous applications of these facts of contrast, to color displays in advertising, dress, etc. More striking color effects may be obtained by the juxtaposition of complements. A yellow blouse becomes more vivid above a blue skirt. A blonde can accentuate her blondness with a dark hat; a brunette can obtain striking effects with items of white.

**Successive Contrast.** Similar effects are obtained when color and brightness stimulation follow in succession, instead of acting simultaneously. Just as a grey appears darker on white than on black, so it looks darker *after* fixation on a bright surface

and lighter after looking at a dark one. Adjacent complementary hues strengthen each other, as noted above; when they follow in succession the saturation of the second color is similarly increased. In fact, by prolonged fixation of a color before shifting the eyes to its complement, one may induce color experiences of a richness far exceeding those to be found anywhere in nature, or in the spectrum. Visual sensations may be aroused by such means which cannot be reproduced by any form of physical stimulation (direct). If the eyes are shifted, after fixation on a color, to a grey or white surface, the complementary color will appear; this phenomenon is called an *after-image*. Obviously there would seem to be a close relationship between the induction of complementary after-images in successive stimulation, and the similar induction of complements on adjacent surfaces with simultaneous stimulation. The point will be mentioned again in the discussion of color theory.

*After-images.* There are two forms of these, called *positive* and *negative*. Positive after-images are a brief continuation of the primary visual impression. If one fixates a light bulb emitting white light for a few seconds in a dark room, and then quickly cuts off the light by interposing an opaque screen in its path, the luminous image will persist for an instant, then vanish. The response remains active for a moment after the withdrawal of stimulation. Immediately after the disappearance of the positive after-image an image of the same form may be observed which is *darker* than the surrounding field. This latter image, with its opposite brightness value, is called the "negative" after-

FIG. 42. For demonstration of the brightness after-image. (From Gates, Elementary Psychology, The Macmillan Co.)

image. If the reader will steadily fixate Figure 42 for about one-half minute, then transfer his eyes to a white surface, a negative brightness after-image will appear.

It will be recalled from the discussion of visual adaptation that a period of darkness causes the retina to become increasingly sensitive to illumination—painfully so, in fact, when daylight is abruptly restored—and that the eyes also become "used", or adapted (less sensitive) to high illumination as it is continued. Accordingly, the white and black portions of the figure fixated, as above, will produce areas of reduced and heightened sensitivity, respectively, on the retina. When the eyes are then shifted to a white surface the areas sensitized by exposure to black will react strongly to furnish an image of vivid whiteness, while the light-adapted area, reduced in sensitivity, responds weakly to the white surface, and this portion of the image will therefore appear greatly reduced in brightness.

Colors also have their after-images, which are likewise of two kinds, though the "negative" variety is in this instance the easier to observe. Fixation on a colored light or paper, followed by transfer to a white surface, will cause a patch of color to appear whose hue is complementary to that of the object fixated. This is called the *complementary* after-image. If, as noted above, the after-image is projected, not on a neutral surface but on one complementary in color to the object of primary fixation, a marked increase in saturation is observed. After staring at a small square of blue paper, for example, and then shifting the gaze to a larger sheet of yellow, a square of very rich yellow will appear on the latter, surrounded by a yellow of lesser saturation. If, instead, a blue sheet is substituted for the yellow, in the secondary fixation, a blue area of *reduced* saturation will appear. In brief, when the two fixation surfaces are complements, the saturation is raised when the after-image is projected on the second; when the surfaces are the same in hue, saturation is reduced by the same means. When, finally, the surfaces are neither the same nor complementary, the results of after-image projection resemble a blending of colors. When the primary surface is blue, for example, and the resulting yellow after-image is projected upon a red surface its hue is inclined toward orange; on a green surface a yellowish green results.

## COLOR THEORY

An attempt may now be made to render some of these many and various visual phenomena intelligible in terms of basic retinal functions and processes. Since the physiology of the retinal activities underlying color experience is very little known, the explanatory formulas in this field are largely systems of assumption. They are designed to weave the observed data into some sort of unity in terms of which the facts of primaries, blends, complements, contrast, after-images, etc., may appear as consistant expressions of certain fundamental visual mechanisms.

The phenomenon of brightness adaptation may well be regarded as an indication of diminished retinal sensitivity. Following a period in darkness, daylight illumination is unpleasantly bright. Sensitivity soon diminishes, however, and visual impressions are reduced to a permanent level of comfortable brightness. Adaptation to color also occurs, though the interpretation of this fact varies. Continuous fixation on a color stimulus results in a decline in its saturation as well as its brightness. If the color is not too richly saturated its hue may entirely disappear. In this condition of the retina any color blend of which the color fixated is a component will be correspondingly modified in hue. It seems established, however, that darkness adaptation is the function of a substance known as visual purple, found in the rods, which is sensitive to very faint light. This substance is bleached out by strong illumination, and regenerates in darkness. Its slow regeneration in twilight, after exposure to daylight, would explain the gradually rising sensitivity in dark-adaptation.

**The Ladd-Franklin Theory.** Of the three outstanding general theories of color vision (the others being the Young-Helmholtz and Hering theories) that of Ladd-Franklin seems to have been least weakened by criticism. It offers a fairly simple and satisfying possibility of explanation of the various facts described, does justice to the psychological data, and provides a plausible account of the evolutionary development of the color sense.

The foundational fact is that to the entire series of graded wave lengths of physical light to which the eye is sensitive, only four primary psychological responses are made. These are the elementary colors: yellow, blue, red and green. In-

termediate wave lengths are experienced simply as blends of these elements: yellow-green, blue-green, etc. It is logical to deduce from this that there must be only a few basic retinal processes which in various combinations can furnish a large number of color experiences.

The theory proposes that color vision has developed, during the process of evolution, from a primordial condition of colorless vision. All wave lengths produced but a single response. A photo-chemical substance was completely decomposed by the action of light of any kind, this chemical change supplying the stimulus to sensations of grey. The periphery of the retina has remained in this primitive stage of development. All colors appear grey in the extreme margin of the field. While this substance reacts to all wave lengths it is most responsive to those in the region of green, which underlies the fact that in low illumination (rod vision) this region is brightest.

The cones in the intermediate zone of the retina, between the periphery and the more central part, have reached a higher stage of development. Here the primitive rods have developed into cones. In this region the primitive "grey substance" has become differentiated into two components, each specialized in its sensitivity, one to the long waves corresponding to yellow, the other to the short waves for blue. In the final stage of development, represented by the central part of the retina, the yellow component of the cones has undergone a further and similar specialization of sensitivity; one of its elements reacts only to the long waves of red, the others to the short waves of green. The central cones, then, contain all of the color components. This complex substance is *partially* decomposed by the wave length for red, similarly for green. If, however, both red and green lights act together on the red-green substance its decomposition reconstitutes the original nerve-exciting chemical stimulus for yellow. It will be recalled that a mixed stimulus composed of red and green lights does result in the disappearance of these colors and the emergence of yellow. If a mixture of wave lengths for both yellow and blue act together upon the cones the *complete* decomposition of the color substance reconstitutes the original primitive stimulus for grey, the response now being the same as that evoked by rod stimulation.

According to this formula it will be seen that a mixture of red and blue-green, and of green and purple (blue-red) will likewise result in complete decomposition of the cone substance, and in the sensation of grey. With a light of wave length *intermediate* between those of two adjacent colors, blue and green, for example, decomposition of the two corresponding color substances also occurs and the resulting experience is the same as that evoked by a mixture of the proper wave lengths, i.e., those for blue and green. Thus complementary mixtures and blends are explained.

Figure 43 illustrates the developmental history of the color sense. The circle at (a) represents the original photochemical molecule whose dissociation provides the stimulus for the sensations of white and grey. In (b) the molecule is differentiated

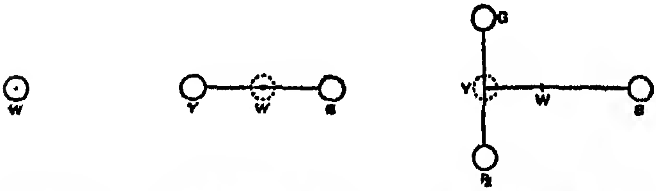


*Fig. 43.* Symbol of the development of color vision according to the Ladd-Franklin theory. (From Christine Ladd-Franklin, Colour and Colour Theories, Harcourt, Brace & Co.)

into yellow and blue components whose partial decomposition furnishes the stimulus for the corresponding sensations, and whose total decomposition re-forms the stimulus for grey. In (c) the final stage is reached in which a similar differentiation for red and green has occurred.

The retinal distribution of color sensibility is given a genetic interpretation. As a target containing the four primary colors is moved from the center of the visual field toward the periphery the green disappears first, then the red, then the blue and yellow, successively. Figure 44 illustrates these zones. Beyond the limits of the yellow-sensitive region lies the achromatic, color blind zone, representing the original, undifferentiated "mother substance." The course of development has thus moved inward toward the macula. Within the color areas a single wave length produces only partial decomposition of the "color molecules," and thereby the sensation of a primary hue

or a blend. Light of all wave lengths in any of the color zones produces complete decomposition, restoring the original excitant for grey. According to Ladd-Franklin (following Ramon y Cajal) the cones are merely highly evolved rods.

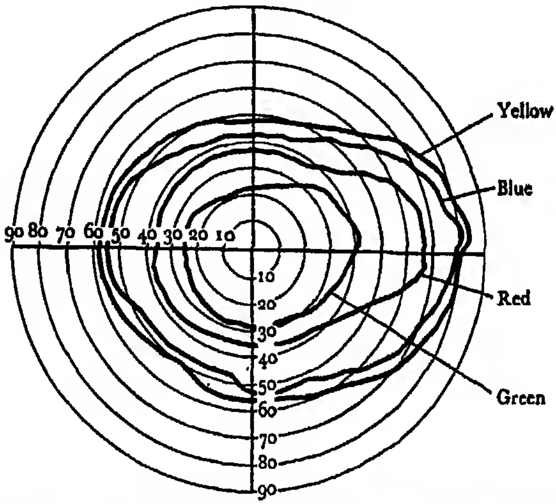


*Fig. 44.* Map of the color zones. (From Bills, General Experimental Psychology, Longmans, Green & Co.)

They contain fundamentally the same photochemical substances, which, however, have undergone a molecular rearrangement expressing in the specialized sensitivity basic to partial decompositions.

Complementary after-images are explained by the theory in terms of the chemical instability of the color molecules of the cones, once partial decomposition has taken place under the action of light. Fixation on blue, for example, results in a break-down of the blue component of the color substance. But this leaves the latter in so unstable an equilibrium, having lost one of its constituents, that the remainder automatically decomposes to supply the excitant for the yellow sensation, which is thus the after-image of blue. According to this theory no external stimulation should be necessary for the after-image, and it is known that these phenomena may be observed in complete darkness. After fixation on red, a similar decomposition of the green and blue substances follows, accounting here also

for the complementary character of the after-image. The heightened saturation obtained by projecting the after-image upon a surface of the same hue can be explained by the more rapid and facile decomposition of the color substance in view of its instability, the process having already begun of its own accord.

The facts of simultaneous color contrast are explained by the assumption that color molecules partly decomposed by light action upon a retinal area do not remain within the boundaries of this area, but are carried away by the rapid blood circulation of the retina. Their completed decomposition after passing out of the area of stimulation induces the complementary hue in the immediately adjacent surrounding regions.

The theory takes due cognizance of the fact that the four psychologically primary colors may be aroused by only three different wave lengths. White, or grey, moreover, is regarded as just as primary as red, green, yellow, and blue. An intelligible and at least plausible account of the main features of color vision is offered. As its originator emphasizes[145], it avoids several of the errors committed by its predecessors, the Young-Helmholtz and Hering theories. It is not, however, free from criticism. Against the explanation given of simultaneous contrast the objection has been raised that the retinal blood circulation is not rapid enough to account for this phenomenon. It is reported that color contrast has been observed under illumination lasting only 1/10,000,000th second.[146] Hecht[147] reports an experiment in which red light was projected upon the retina of one eye and green on the corresponding area of the other; a fusion sensation of yellow resulted, indicating that this process takes place in the brain. If yellow is presented to one eye and blue to the other by means of a stereoscope, a fusion may occur in which neutral grey is seen; non-complementary hues give mixtures. Such binocular interaction must be cortical, and explanations of color phenomena in retinal terms are thus weakened.

## COLOR BLINDNESS

Color experience is not alike for all persons. There are a number of forms of color blindness, some of which are hereditary, others a consequence of retinal disease. The defect is much more frequent in men than in women. It may elude

detection for many years, since there are other ways of correctly naming colors than by means of normal sensibility to hue. Differences in luminosity and in the visual form and surface texture of objects may be associated with the proper color names, so that a color blind person may easily designate grass as green, a rose as red, the sky or the ocean as blue, without actual consciousness of these qualities. He learns that certain color names are consistently applied to certain objects. The characteristic visual pattern—the size, shape, detail, etc., of these objects may thus become a quite adequate sign by which the color designation is applied. All trees are green, and a tree is not readily confused with anything else.

A few individuals are totally color blind and see nothing but a world of greys of different brightnesses. This is equivalent to rod vision; the spectrum of the totally color blind is a scotopic or twilight one, with its brightest region in the green. The most common form of color blindness, present, it is reported, in from 3 to 6% of men, and hereditary in origin, is that affecting vision for red and green, usually called red-green blindness. What appears as red or green to the normal is seen as unsaturated yellow by these people, while mixtures of blue with red or green are seen as unsaturated blue. The spectrum is divided into a band of yellow and a band of blue, with a short intermediate band of grey at the point normally seen as blue-green.

In one of the forms of red-green blindness, called protanopia, there is a marked loss of sensitivity to the long waves, and the spectrum in these cases appears much shorter than the normal. The extreme red end of the spectrum is not seen at all; orange, yellow and green appear as yellows of different brightness; blue and violet as blue. In the second form of red-green blindness, called deuteranopia, the spectrum is not shortened, these cases having retained sensitivity to the long waves; they perceive long wave color as brighter than is the case with protanopes. The grey band of the spectrum lies a little nearer to the long end. The brightness distribution for deuteranopes does not differ much from that for normals.

Normal color vision is called *trichromatic* because any one of the 160 or more distinguishably different hues may be produced by variously mixing the stimuli for three colors (red,

green and blue). *Dichromatic* vision, similarly, means the abnormal form in which only two colors are necessary, by mixture in various proportions, to match any part of the spectrum as it is seen by those with this type of vision. Protanopia and deuteranopia represent sub-groups of dichromatism. The protanopes being relatively insensitive to long waves, different strengths of colors will be required for brightness matches as between the two groups; to obtain an equation of brightness between a yellow and a red, for example, a protanope will require a much more intense red than a deuteranope.

According to the Ladd-Franklin theory total color blindness and red-green blindness represent early stages in the development of the color sense. In the former the entire retina is in the first stage; in the latter the central area has remained in the second or yellow-blue stage.

## MENTAL FACTORS: TRANSITION FROM SENSATION TO PERCEPTION

Visual experience has been discussed, thus far in this chapter, as a function primarily of stimulus factors and retinal factors. It has been obvious that a number of visual phenomena cannot be accounted for by reference to physical stimulation alone. There is no invariable relationship between given brightness and color stimuli and the brightness and color responses which follow. The facts of adaptation and contrast make it clear that the variables of visual sensory physiology may very markedly modify the conscious visual reactions to physical stimulation. It is now time to devote a few words to some of the facts indicating that there are psychological as well as physical and physiological determinants of our impressions of color and brightness. These facts were very briefly touched upon in the chapter on Visual Perception, under which heading, in a more proper way, their discussion belongs. It has been thought advisable, however, to deal with them at the present place in view of their intimate relationship to the immediately foregoing topics.

**Brightness Constancy.** This term is used to designate the fact that our conscious brightness impressions of objects vary much less than does the physical basis of such impressions. Objects appear to maintain a certain standard brightness despite frequent changes in the amount of light they reflect owing to

changes in illumination, shadows, etc. We tend to see white objects as white, and black objects as black, even under conditions in which the black surface, by special intense illumination, reflects as much light as the white surface. In such a case the retina is being stimulated with equal intensity by the two surfaces; nevertheless the observer continues to see things "as they really are"; that is, he sees a *black* object under intense lighting, and a *white* object under low lighting. What appears to have taken place is a process amounting to an automatic discounting of the difference in illumination, since the observer is aware of the illumination as well as of the object illuminated. This kind of experience is comparable to the perceived constancy or stability of the position of objects after a change in the position of their retinal images. The latter phenomenon, it will be recalled, was interpreted to mean that the mind reacts, perceptually, to the total sensory impression, which includes sensations from the postures of the eyes as well as those resulting from retinal stimulation.

The phenomenon of brightness constancy, in the above instance, may similarly be explained as an indication that the response is made, not to the specially illuminated object alone, but to the condition of special illumination itself, as well. The brightness of the object is viewed within the frame, so to speak, of the brightness of its special setting. Under other conditions awareness of changes in the general level of brightness of all surrounding objects functions to maintain the relative brightness constancy of a particular surface. As twilight comes on the greying papers on my study table remain "white" papers because I am conscious, as I view them, of the lowered general brightness of all objects in the field. *Relative* to the luminosity of environing surfaces the white papers are still the brightest in the field. The total visual context thus determines the response to these particular items. I see, not a grey surface, but white-in-twilight. Such reactions do not, of course, represent anything in the nature of "deductions." The observer simply becomes "set for illumination," as Woodworth says. In the same way the perceived brightness value of a black surface under high illumination is a function of its illumination. Relative to the amount of illumination it *receives*, the black reflects very little, and is therefore perceived as black. Brightness con-

stancy has been experimentally observed in the percepts of young children and in certain species of the lower animals.

This interpretation may be tested in a simple fashion by excluding the visual context responsible for brightness constancy. A white paper, in twilight or under a shadow, is seen, as stated above, much lighter than can be accounted for by retinal stimulation. We should see it, in other words, as darker than we do were it not for our perception of the conditions of illumination. If the latter factor is removed by viewing the object with one eye, through a tube, or by means of an opaque screen with a small hole in it—a "reduction screen"—permitting vision for only a part of the surface, brightness constancy breaks down and the surface is seen in accordance with the amount of light stimulation. The paper is seen, not as a white in shadow, but as a dark surface. By the use of such reduction screens under controlled experimental conditions the amount of brightness difference due to the constancy factor has been quantitatively determined and found to be surprisingly large.[148] Two grey surfaces, e.g., seen as identical in shade by the observer under conditions in which the constancy factor was operating, were found by actual photography to be markedly different in brightness. One of the greys, in this instance, was raised above its true brightness value to a point where it matched a lighter grey when the conditions of illumination were apparent—i.e., in the absence of the reduction screen.

**Color Constancy.** This term similarly denotes the fact that object colors tend to remain relatively unchanged during changes in the quality of illumination, and therefore during changes in the character of retinal stimulation. The facts of color constancy suggest the same psychological category as those of size and form constancy discussed in Chapter IV. Objects are perceived as invariable in size despite variations in the size of the retinal image; they are perceived as stable in form through many perspective distortions of the form of the image. Hues manifest a comparable stability. Under red illumination a white surface appears suffused with a reddish tint. When the surface is viewed through a tube or a reduction screen this tint is more marked; under normal conditions the constancy factor tends to preserve the whiteness of the surface. It is stated that a green surface in red illumination remains

perceptually greenish, but tends toward grey when viewed through a screen.[140] A green object under blue light strong enough to cause a greater reflection of blue than would normally an object actually of this color, is still perceived as a green object. If a colored object illuminated by light of a different color is viewed through a reduction screen, it appears definitely tinged with that color. The effects brought about by exclusion from view of the illumination factor have been called *color reduction,* and the colors seen under such conditions are called *film-colors,* as opposed to the *surface-colors* seen under ordinary lighting conditions.

**Film- and Surface-Colors.** The latter are for the most part the colors of everyday experience. They are perceived as the colors *of* objects. They exhibit solidity and spatial definition; they *reside* in objects, along with the visual pattern and surface texture—rough or smooth, hard or soft. These colors, as has been stated, are perceptually distinguished from their illumination, high or low, shadowed or unshadowed, colored or uncolored. They possess body, are material, tangible. The device of color and brightness reduction removes all these features by excluding the visual stimuli which normally underlie our consciousness of them. The experience in such instances represents solely the response to local retinal stimulation. They are a close approach to *pure* visual sensation, according to our earlier definition. The characters of solidity and of a definite locale in space, i.e., of depth, hardness and distance, are absent. The blue of the sky has been suggested as an example of a film-color. Such colors are disembodied; they are not seen as parts of objects but as indefinite spreads of hue suspended in space. Perspective features are likewise absent. If a surface placed at an angle in relation to the line of vision is viewed through a reduction screen the impression of obliqueness is absent from the visual image. Such studies afford beautiful demonstrations of the fact that visual perceptions are integrated composite reactions aroused in response to a total stimulus constellation comprising many features. A number of these were discussed in Chapters IV and V. The present section merely adds the factors of special and general illumination to the long list of visual signs.

The experience formula may be applied to color constancy in the same manner in which it was applied to visually perceived size and form. Objects seen under "standard", usual, or daylight illumination are seen in their "true" colors. Within the context of secondary—accidental and temporary, colorings, this true color or "memory color" continues to be seen. Along with this there operates the "relativity principle"—the colors and luminosities of objects are perceptually "judged" always within relation to the criteria of special and general illumination. The presence of shadows which reduce the physical intensity of the image have no more influence on our impressions of its "real" brightness than the angle of view which causes a circular table to cast an elliptical image influences our percept of its real circularity. Even where the constancy phenomenon is manifested under conditions in which foreknowledge of the true color and brightness of the surfaces is absent, it is certainly permissible to assume that experience is the basis of the accuracy of judgment. We must learn, that is, the relationships between illumination and illuminated objects.

Our concrete color and brightness experiences represent, then, perceptual transformations of the retinal data. Visual "reduction" is reduction to sensation. The latter is a relatively fixed function of physical stimulation and physiological activity, while percepts express the more fluid process of interpretation, grounded in experience and influenced by special training.

## Chapter VIII

# ILLUSIONS OF VISION

Vision is subject to deception more frequently and variously than any other sense. "Seeing is deceiving"—to quote one writer's version of a familiar adage, and since believing often accompanies such illusory impressions it may be well for the student to be familiar with the main features of a few of them. It was shown earlier that the images of one and the same object may be surprisingly changeable. In so far as any one of these fluctuating appearances of an object is still adequate to evoke its recognition it is said to function as a sign of that object, and these signs, in the visual field, reach a very high degree of multiplicity and attenuation. The visual system is, in a sense, extremely versatile; a given response may be touched off by slight and remarkably diverse stimuli. The fact doubtless contributes in some measure to the susceptibility of this sense to erroneous reactions.

The term visual illusion is here used to designate any visual impression or feature of such an impression which does not "check" with or correspond to the characteristics of the physical object. More briefly, it is an instance in which the visual system supplies false information about an object to consciousness. In this statement "visual system" includes not only the retina and its cortical projections but also the cerebral organizations whose function is to give immediate meaning to things seen.

The "false information" may take an almost inexhaustible number of forms. Seeing a line as curved when it can be proven straight; seeing a surface as colored when "actually" it is colorless; seeing an object as moving when it is stationary; seeing two forms as differing in size when they are identical in dimensions; seeing what is apparently a body of water before

one when in reality there is no water present—these are fairly typical of the illusions.

In all of them reality is visually mis-reported; our impressions of things are in some way distorted in form, in some way fail to be authentic versions of the attributes of things. In some cases they may even report data which are physically non-existent; in this case our definition would partially overlap that of hallucination. While some of the above statements would require further refinement and qualification to be acccurate from a philosophical point of view they will suffice for elementary purposes.

It may be stated at the outset that many illusions of vision are not deceptive. In a number of instances, while the illusion may be experienced by everyone, almost no one is *deluded* by *it*, i.e., does not truly believe that the facts are as they seem to be. To take the simplest illustration, no one believes that a roadway really becomes narrower in the distance, despite the fact that it "looks" that way, or that an echo means two sounding bodies instead of one. In the same sense, and depending on the experience or "sophistication" of the observer, a number of so called illusions are not in the least deceiving; belief is not aroused by the visual impression. No one but a child, for example, believes that a stick immersed in water becomes bent, despite its appearance. Even a person who is unable to explain this fact in terms of the refraction of light realizes none the less that a distortion has somehow occurred. A student of illusions, unless, as in certain instances, he deliberately trains himself to be less subject to them, is generally just as liable to them as anyone else, but he is far less likely than the layman to be deceived by these appearances. He has learned some of the principles of sensory distortions and "phantasms" and makes allowances and correction for them.

The division of the materials on illusion into the four sections of this chapter is intended primarily to impose a little order upon a large and heterogeneous field. In the case of the first three of these sections the terms "physical", "sensory", and "perceptual" are derived from the causes of the phenomena described. That is, physical illusions are explained wholly in terms of the concepts of physics; sensory illusions in terms of the sense organ and its primary cortical projections, i.e., to

certain features of the way in which the afferent physiological processes go on; perceptual illusions, as the term suggests, derive from the secondary organizations which confer meaning; they are the product of the associative process. The fourth class of "geometrical" illusions will be recognized by many as a conventional one, deriving its name from the character of the forms by which it is illustrated, and obviously with no implications as to causes. The number of these is very large; those included here are intended only as samples. The explanatory theories are likewise numerous; accordingly only a few can be given. Since few of the theories have won to any very general acceptance, only those are presented which have achieved a fair reputation for plausibility. It is also to be stated that the classifications under the headings of "sensory" and "perceptual" are in some instances tentative rather than final. The cases to which such qualification applies will be indicated.

## PHYSICAL ILLUSIONS

There are certain illusions which take place within the field of vision—and are therefore in a sense "visual"—which owe their origin to purely physical conditions. The experience fails to check with reality, but here no part of the visual system, peripheral or cortical, is responsible. Neither the eye nor the mind is at fault. These illusions, properly, are thus not psychological at all; they are very briefly mentioned merely to establish the limits of the psychological study, and to show that there are visual deceptions in which the eye itself is not the deceiver.

When a ray of light passes obliquely from one medium to another, its direction will be changed and this change is called refraction. If the ray passes from a medium of greater to one of lesser density, as from water to air, the refraction or bending is away from the perpendicular, its amount depending on the obliqueness of the ray and the kind of light. In Figure 45 the ray of light coming from the coin $x$, resting on the bottom of a pan of water, is refracted at the surface and passes to the eye at O. It is seen projected in the line $Oy$ and is therefore seen as elevated above its true position. The bottom of the pan will likewise be displaced and appear shallower than it is.

A more spectacular example of an illusion based on refraction is the mirage. In the above example the refraction is the

result of the passage of rays through two media of different density and therefore different indices of refraction. A comparable situation arises when several layers of atmosphere, ow-

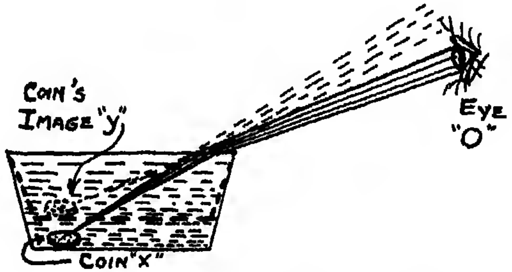


*Fig. 45.* Image displacement by refraction

ing to unequal heating, have different densities and ray-bending powers. In desert countries the air strata along the ground may be heated to high temperatures and have a low index of refraction, which will increase with cooler temperatures and greater densities at higher altitudes. The rays of light leaving the mountain top at *A*, Figure 46, in the downward direction

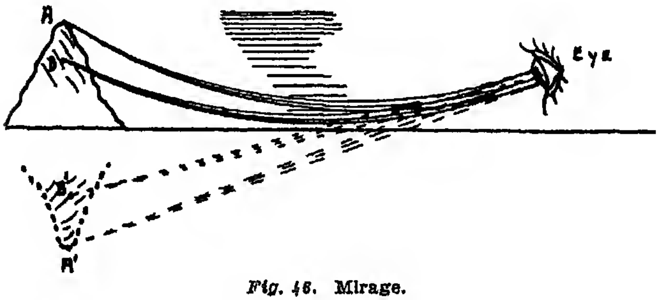


*Fig. 46.* Mirage.

represented would under ordinary conditions strike the ground. The lower portions of the wave-front are less refracted than the upper portions, however, with the result that the beam is swung about upwards again in a curved line eventually reaching the eye. The mountain top is therefore seen projected at *A′*, producing an inverted image. The rays may likewise come from the sky just above the horizon; a blue expanse will then be seen below the horizon and perhaps be perceived as a body of water. Not uncommonly such experiences are reported

by motorists; what appear to be pools of water are seen extending across the road. If the distribution of atmospheric densities is such that the rays are bent in an upward-curving instead of a downward-curving arc, objects will be projected above the surface of the earth. In Figure 47 the rays from

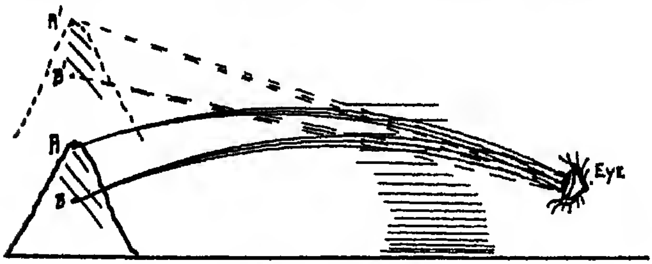


*Fig. 47.* Mirage.

the mountain top which ordinarily would pass off into infinity are bent back toward the earth and finally reach the eye of an observer who will see the object suspended in space, since it is located in line with the direction of the rays entering the eye.

The foregoing account of the mirage has been proven by an interesting experiment.[150] A series of metal plates are mounted on tripods to form a flat surface about ten feet long. This is covered with sand. A mirror is mounted at one end at an angle causing it to reflect the sky toward the observer stationed at the opposite end. This reflected sky is seen as extending down to the "horizon" formed by the far end of the plates. Some small pasteboard models of mountains are placed on the horizon. The plates are then heated by a long gas-burner. If the observer then looks down over the "desert", his eyes close to the surface, he sees what appears to be an expanse of water on the sand, in which the inverted images of the mountains are reflected.

A mirage is not, therefore—contrary to occasional popular belief—a kind of hallucination. It is a physical phenomenon which may be observed by anyone when present. Photographs of mirages have been taken. Such illusions have been suggested as the explanations of otherwise mysterious airplane accidents; the sidewise displacement of a mountain peak, for example, might dangerously deceive a pilot.

## SENSORY ILLUSIONS

These, as previously defined, arise from certain characteristics of the primary visual function—the activities of the retina and its cortical projection. Since some of these phenomena have already been discussed in the chapter on sensation it remains merely to indicate that they may properly be included in the category of illusory experiences.

The facts of color and brightness contrast will be readily seen to exhibit features which justify their consideration as illusions. When an observer reports that a line appears curved to him notwithstanding its demonstrable straightness as attested by aligning it with a ruler, we say that an illusion has occurred. Similarly, if he reports two patches of gray to be unequal in shade when viewed, one on a white, the other on a black ground, he is again subject to illusion, provided the grays appear identical in brightness when placed on the same ground, the latter being the "ruler" in this case.

The phenomena of color contrast may likewise be listed as illusions; that is, the production of complementary color-fringes by placing a color upon a neutral ground; likewise the enriching of a color by placing it upon a complementary ground. We are dealing here with color impressions arising in the absence of the customary retinal stimulus. The blue contrast-fringe surrounding a yellow square placed on gray is experienced without the corresponding wave-length for blue, just as (while ordinarily we must stimulate the retina with a curved line if we are to see one) a straight line will appear curved if certain geometrical patterns are drawn through and around it. The white star in Luckiesh's demonstration could be given any color by changing the color of the ground; this, as he says, is an illusion by any definition of the word. Under the conditions of Luckiesh's experiment the illusions could be *delusions* as well, since the observer might easily be unable to distinguish between contrast effects and pigment colors. After-images may also be listed; since they may be observed with the eyes closed, they cannot be included with effects arising from the distortion of external stimulation. The boundary between illusion and hallucination becomes somewhat obscured at this point; the latter, as is recognized, cannot be defined altogether in terms of the absence of external stimulation.

The phenomena of sensory adaptation also belong here, by definition. The diminishing brightness of the daylight after emergence from a darked room; the diminishing gloom of a theatre as time passes; the disappearance of an odor with continued exposure to it; the decline in richness of a taste; the apparent fall in temperature of hot water; all of these are illusions if the term is to be consistently applied. Again, the change in hue of colored test-targets as they pass from the periphery to the center of the visual field; the twilight changes in brightness of the colors of a landscape, known as the Purkinje effect; the augmented saturation of colors resulting from contrast influence and seen in paintings, in color-printing and in dress, may further be mentioned. If the generation of stereopsis by image disparity is a sensory phenomenon the visual depth impression obtained by viewing flat photographs or diagrams stereoscopically would be listed in this section; likewise the previously mentioned "pseudoscopic effect."

Illusions of Motion. The illusion basic to motion pictures is a very important one in the world of entertainment. Not everyone knows, perhaps, there is no movement on the cinema screen, and that the screen is in total darkness many times per second. Each individual photograph composing the film must be projected as a stationary image; if it really moved all we would see would be a blur. The movement experience obtained from this rapid (24 per second) series of "stills" is related closely to such more familiar instances as the solid circle of light observed when a torch is rapidly whirled; to the continuous streaks of luminosity seen in fireworks displays; the motion impression produced by advertising signs when a series of electric bulbs is flashed on in quick succession; the mixing of colors on a rotating disc.

As was stated earlier in the text, retinal images persist for a few thousandths of a second following the withdrawal of stimulation. A period of physiological inertia is present both after and before stimulation. The image of a "still" thus remains on the retina for a very short time after the light ceases, but long enough to bridge the interval of darkness between one picture and the next, and long enough so that the next "still" will have cast its image on the retina before the preceding has faded. A shutter revolving in the path of light is timed to

shut off all illumination while each picture is moved into place for projection. The movement must be rapid enough so that a new (and slightly different) retinal image is aroused before the preceding image has become inactive. In this way stimulation is provided that is sufficiently similar to that supplied by a moving physical body so that the same motion impression results.

The explanation, however, may not be so simple as this, and some believe that experience plays a part in the motion illusion; that the rapid series of stationary images simply provides the "reduced stimulus" for the percept of continuous movement.[151,152] Others suggest that the after-image version is too mechanical; that the answer lies in the peculiar dynamics of brain activity under certain types of stimulation. The reader will recall here the earlier description of the Gestalt studies of "apparent movement." Whatever the final verdict on the problem may be, it is undeniable that the "movies" are a true illusion and probably the most spectacular of them all.

Motion, like color, has its after-image, and the latter is the root of a number of curious illusions of vision. A variety once exploited by advertisers involved a rotating disc on which were painted heavy spiral bands in such a manner that the bands seemed to move to the edge of the disc as it turned. A placard instructed observers to gaze at the disc for a few seconds and then to look at some stationary object. Those who did so found that such objects exhibited a curious inward-flowing or shrinking motion. The illusory movement impression in such a case will be opposite in direction to that of the original stimulation. A similar effect is obtained, according to James, if after gazing at the water rushing along the side of a moving boat we then look at the deck; a portion of the latter will appear to move in a direction the reverse of that of the water.[153]

Prof. W. R. Miles has described a number of such illusory effects.[154] A landscape viewed from the observation platform of a train recedes rapidly from us as we speed along; immediately after stopping we may detect an apparent motion of the roadbed toward us. But as we travel forward in an automobile we may observe the impression that the clouds and the sky are *receding* in the direction of travel "as if driven by

a rapid wind." Similarly in forward travel in a train, if we notice carefully, while the lower part of the visual field is rushing in toward us, the upper part will seem to move forward and away from us in the direction of travel. In either case, Prof. Miles suggests, it is as though there were an axis about which the upper and lower portions of the field seem to revolve, the axis coinciding with the point of fixation, lying at the horizon if we set our gaze upon that, or nearer if we fixate nearer. Again, if we sit "backward" at one end of a coach and give our attention peripherally to the passing landscape on both sides, there will be a "compensatory" motion impression in the central portion of the field, and the opposite end of the coach will seem to be coming toward us. The illusion is reversed if we turn around and face the direction of travel. In general it appears, as this writer indicates, that the visual field exhibits compensatory functions. When motion stimuli operate in one portion of the field, processes expressing in the experience of opposed motion are induced in adjacent portions. The reversed direction of motion in the after-image naturally suggests comparison with the induction of complementary color after-images and with contrast effects.

If a stationary spot of light is fixated in a darkened room for several seconds it will begin to move slowly in an irregular fashion. The apparent movements may be horizontal, vertical or circular. They may have an amplitude of as much as 40°. There is no change in the location of the image on the retina during this motion; it occurs with careful fixation of the unmoving point. No other objects must be present in the visual field to serve as reference points. The illusion was first observed over a century ago by an astronomer who noticed that an isolated star appeared to move. It is called the "autokinetic phenomenon" or the "autokinetic sensation," and has not yet been explained.

## PERCEPTUAL ILLUSIONS

The preceding section dealt with certain experiences of the type called illusory which appear to be rooted in the natural modes of sensory organization and operation. The eye, in these examples, has deceived the mind or may at times deceive it. The sensory process here supplies data which report falsely on fact, data which are equally real whether received with convic-

tion or with complete disbelief. The present group, on the other hand, represents those in which, while the sensory data are valid, the aroused memory associates err by falsely interpreting the stimulation. It is *meaning*, in these cases, which fails to check with the facts; past experience garbles the account of conditions rendered by the receptor. The mind deceives the eye.

Among the simpler instances of this kind are those of "memory-overlay" which were touched upon previously. Adams[156] furnishes good examples. "I was walking up the street and saw P. coming toward me on crutches. I saw her very plainly and noted her slim figure and athletic build. I was surprised, however, to see her on crutches, for I didn't know she had had an accident. For this reason I continued to look at her, and I suddenly realized that it was not P. Immediately she became much fatter and her whole physique changed. I was amazed that I could have ever thought she was P." Again: "Until I was eleven years old my hair was of a medium shade of brown. When I was eleven, however, I had an illness and lost most of my hair. The new hair which came in was quite dark. . . . Even now—ten years later—when I see my hair in the mirror casually I see it as light and am startled when anyone likens it to hair which I see as much darker. When I look at it critically, however, it is always dark."

Misjudgments of distance offer examples of illusion of the perceptual type. A familiar one is the underestimations of distance made by tourists in regions having an unusually dry and clean atmosphere. High visibility of detail and sharpness of outline, it will be recalled, are a mark of nearness. In climates having a moderate degree of atmospheric vapor, smoke and dust, marked clearness must mean proximity. When this sign operates in the absence of its usual significance, i.e., where fairly distant objects are clearly visible, as in the high Rockies, distance illusions will be frequent until the observer develops a new set of meanings for the old signs. A larger scale of distances must now be associated with good visibility.

Illusions of mistaken identity, of which an example has already been given, show nicely the process by which a fragment of the usual visual pattern evokes the complete perceptual reaction. A feature very characteristic of a familiar person,

e.g., a distinctive quality of carriage or profile, or an item of clothing, is encountered in a stranger and immediately touches off recognition despite the presence of other details which are for some reason overlooked. Incomplete observation is thus a factor; closer inspection instantly corrects the interpretation. A previously mentioned motion illusion sometimes experienced in train travel was similarly indicated as the consequence of incomplete reaction. The individual jumps to a perceptual "conclusion" on the basis of too small an amount of sensory data. Expectation and preoccupation contribute strongly to such errors.

The close relationship between size and distance in perception has already been discussed. The apparent size of a known object is a rather reliable index of its distance. Conversely, the perceived *size* of an object may in some cases be largely determined by its perceived distance. If of two trees which have approximately the same apparent size, i.e., whose retinal images are equal in magnitude, one is perceived as farther away than the other, it will also be perceived as the larger. It *must*, of course, be larger if it is to furnish an equal image from a greater distance. Here again perception checks with the fact rather than with the retinal image. By the same logic if the distance of an object is underestimated, its size will be likewise underestimated. If we learn that a mountain judged to be twenty miles away is really fifty miles away we will "see" it as a larger mountain notwithstanding that the retina records its image no differently.

An illustration is furnished by Figure 48. The three columns are drawn equal in size yet are perceived as unequal. Their retinal images, assumedly, are identical. Owing to the perspective lines which operate as third dimensional cues, the columns are seen as at different distances and therefore as of different sizes. The point may be made clearer by analogy with the stereoscopic illusion. The depth impression received in viewing a landscape may be faithfully reproduced by means of photographs and a stereoscope. In either case the stereoscopic effect is produced by the disparate patterns of binocular stimulation. Given the proper receptor stimulation, that is, the depth impression will follow, whether the object perceived actually has depth, like the landscape, or whether it consists of flat cards.

With similar reasoning, if we observe at different distances along an avenue three buildings which happen to be equal in apparent size, we shall none the less perceive them as unequal, as they must be to cast such images from different distances. The impression obtained in such a case will be the same as that given by Figure 48, except that it will be a non-illusory percept,

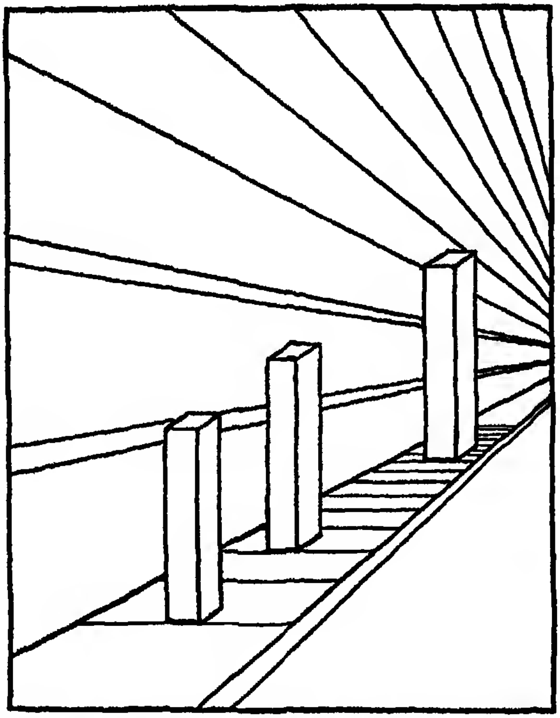

*Fig. 48.* Illusion based on the perceptual relationship between distance and size. The columns are identical. (From Luckiesh, Visual Illusions and Their Applications, D. Van Nostrand Co.)

the dimensions of the objects being seen as they actually are. The figure presents an illusion because it furnishes the stimulation for a percept of size differences in the absence of such differences in the objects themselves, just as the stereoscope gives depth impressions in the absence of any objective depth. To be perceptually equal in size the columns in this figure would have to be objectively unequal,—would have to be successively

reduced "in perspective." If objectively equal they will be perceptually unequal so long as the perspective lines are present. The diagrammatic character of the figure gives it a certain strangeness. Greater realism would be obtained if, for example, actual buildings were represented, the dimensions remaining the same. The illusion would still be present but it would be more like a picture, less a "trick drawing."

Objects are often observed to appear larger than usual when seen through a fog. The illusion is similar to the foregoing except that here the obscurity of outline and detail is the distance sign operating. Perceiving objects, accordingly, as farther away than they are, we perceive them as larger than they are. The opposite illusion occurs when underestimation of distance, owing to unusual clearness, leads to underestimation of size.

An explanation offered for a long-discussed illusion is of the same character. The sun and moon appear to be considerably larger at the horizon than at the zenith. That the phenomenon is not the result of physical factors is demonstrated by photographing the bodies at both positions. No change in their diameters is registered. The illusion must therefore be psychological. The suggestion that the enlargement results from the fact that the sun and moon appear to be farther away at the horizon than when directly above dates from the ancient astronomers and was favored by Helmholtz and other modern authorities. The distance illusion is thus basic to the size illusion, and is itself the consequence of the form of the sky, which owing to cloud and mist layers is that of a flattened vault instead of a hemisphere. The sky, that is, appears to be nearer at the zenith than at the horizon, and the sun and moon are seen as located in or "at" the sky. The logic is clearly similar to that of the foregoing cases; here the form of the sky serves as the "perspective sign." Other theories involve the influence of atmospheric perspective, size contrast with adjacent objects, etc.[156,157]

One writer on vision[158] offers a simple but interesting personal experience illustrating the same formula. "The author looked out of his back door one day and was much perturbed by seeing what appeared to be a striped yellow tiger crawling along the top of a fence some distance away. A second glance

showed that it was a striped yellow cat crawling along the top of a fence between himself and the farther fence where the cat first appeared to be. Over-estimation of distance caused an over-estimation of size." This author happens to be blind in one eye; such an illusion, as he states, would be more likely to occur in monocular vision, in which the visual distance sense is less acute.

A further example, in which the opposite illusion of size occurs, is seen in Helmholtz's explanation of the diminished perceptible size of objects seen out of the windows of a fast-moving train. As everyone knows, the closer things are the more rapidly they move across the visual field as we travel past them. Quick passage therefore becomes a sign of nearness. The greater the speed, then, the nearer objects are perceived to be; retinal size being constant, houses and trees tend to be perceived as smaller than usual because they seem nearer.

The influence of the perception of distance on that of size has been sufficiently illustrated. Errors in the judgment of size may in turn lead to misperceptions of distance. It will be recalled that when the "real" or close-up size of an object is known, its "apparent" or reduced size functions as a distance sign. However, misjudgments of "real" size may easily occur. A tree is a tree, of course, but trees differ considerably in size, likewise houses, ships and mountains. Mistakes in the perception of actual size will entail corresponding errors of distance estimation. Knowing a certain mountain to be two miles high we might judge its distance fairly correctly on the basis of an image of a given size. If, on the other hand, we falsely think it to be five miles high we will overestimate its distance, for it would have to be more distant at such a size to supply the same image. Similarly, if we think it only one mile in height we will perceive it as nearer than it is, for to cast the same image, yet be so small, it would have to be closer. So, while the smaller the image of an object of known size, the farther it is perceived to be, yet, with an image of a given size, the smaller the *object* is perceived to be, the closer it will be judged.

The explanation cited of the horizon-zenith illusion, it may be mentioned in passing, was offered as an illustration of the size-distance formula, rather than as an accepted solution of the problem. This phenomenon has been experimentally in-

vestigated by means of a small-scale reproduction of the conditions.[159] Circular discs of light were projected forward to the walls and upward to the ceiling at various distances ranging from 3 to 32 meters. The size of the discs was varied until the observer reported them equal. The objective difference in size necessary to make the discs appear equal was then taken as a quantitative measure of their subjective inequality when physically identical. It was found, for example, that at a distance of 22 meters the overhead disc had to be nearly twice as large as the lower one in order to appear equal. The sizes for the overhead disc had to be larger for all distances, and in proportion to distance; this was true even for 3 meters. Apparent diminution for the overhead disc were reported with the observer in different positions. Comparison was made with the observer lying on his back, one "moon" on the ceiling and another on the wall behind him. The latter disc, in this case corresponding in position to the moon at the zenith, again appeared smaller. The direction of the visual axes thus appears to be a factor.

Another "celestial illusion" is the familiar one obtained as we watch a cloud pass across the moon. We perceive just the reverse of this; the moon in motion, passing behind the stationary cloud. Knowledge of the facts does not affect this impression, any more than it affects that of the apparent movement of the sun across the sky. The experiment of Van Waters described in Chapter V disclosed some of the determinants of motion perception which are illustrated here. There was a tendency to perceive the larger object as stationary, the smaller in motion. Illusory movement was more often associated with fixation, and it is usually the moon that is fixated when the above impression is observed. Slowness of movement was found to increase the tendency to illusion; the movement of clouds is ordinarily slow. There are, moreover, no fixed reference points except the inconspicuous stars.

There is an inclination to perceive the smaller of two objects as the more "mobile." This term refers, in the above-mentioned experiment, to the tendency of an object to be perceived as in motion when stationary. The greater perceptual "mobility" of small objects and the greater stability of larger ones has been attributed to experience with the world of objects in

general, the greater magnitudes on the whole being associated with things that do not move. A simple experiment[100] demonstrates a similar association between size and weight. The subject is presented with two boxes identical in every respect but size; he is asked to compare their weights by "hefting" them. Usually he underestimates the weight of the large box, overestimates that of the small one. The latter contains lead shot, the former wax; the weights are the same despite the difference in size. Expecting the larger to be the heavier the subject lifts with greater initial effort, by comparison with which the box is surprisingly light. The smaller box, on the contrary, is found unexpectedly heavy in proportion to its size, and is overestimated in weight. The visual illusion in which weight is falsely, in this instance, correlated with size is primary here. It underlies the ill-adapted preparation of effort which leads to the erroneous judgment as to weight.

Expectation or habit similarly plays a part in the motion illusion sometimes experienced when a train adjacent to our own moves backward and we perceive ourselves as in forward motion. A *forward* motion of the adjacent train seldom causes us to perceive ourselves as moving backward, since this is counter to our expectation. The first illusion is quickly dispelled by a larger visual intake which includes stationary reference points. When the actual starting of the observer's train is unusually smooth he may perceive himself as stationary and the adjacent train as moving backward. Auditory and bodily impressions usually prevent this illusion. It is clear that numerous factors, visual and non-visual, are operative; the chance absence of some one or more of them, together with momentary conditions of attention, expectation, etc., provide the possibilities for an adequate explanation in most instances. Accurate visual perception of motion and of other facts as well will be favored by supplementary data from other sensory sources which will corroborate or contradict, as the case may be, those of vision itself.

## GEOMETRICAL ILLUSIONS

Of all optical illusions the geometrical variety seems to have held the greatest appeal for psychologists. Many studies have been made and a large literature of discussion has grown up centering around these peculiar phenomena of vision. The more

common types will be presented, along with some of the theories offered in explanation.

Figures 49, 50 and 51 illustrate the principle of *contrast*, according to which our impressions of size are strongly influ-

*Fig. 49.* The middle sections of the lines are equal. (From Luckiesh, Visual Illusions and Their Applications, D. Van Nostrand Co.)

enced by the relative size of adjacent figures and areas. The middle sections of the lines in Figure 49 are equal in length but appear unequal owing to the influence of the adjacent lines. The student can easily apply this concept to Figures 50 and

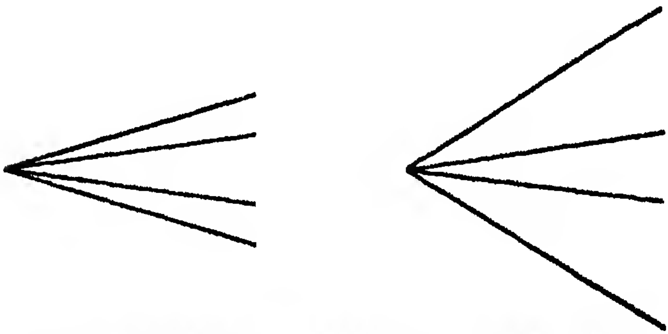

*Fig. 50.* The inserted angles are equal. (From Luckiesh, Visual Illusions and Their Applications, D. Van Nostrand Co.)

51. Such terms as large and small, long and short, etc., are in themselves meaningless; only by reference to a standard do they acquire significance. The center circle in Figure 51 (a) is "large" by comparison with the surrounding circles; that of (b) is "small" by similar comparison. The same general fact was illustrated in the illusion exemplifying brightness contrast; there are numerous instances in sensory fields other than vision, e.g. in the case of temperature, taste, kinethesis, when the stimuli are presented successively.

The Müller-Lyer illusion has long been a classic. Three examples of it are given in Figure 52, the topmost form being the more familiar version. The pairs of horizontals are equal in length but appear unequal owing to the influence of the lines drawn at their ends. According to the *eye movement theory*

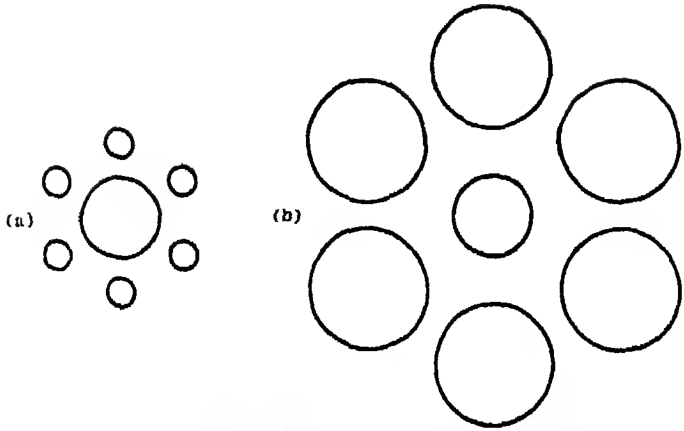


*Fig. 51.* The center circles are equal. (From Luckiesh, Visual Illusions and Their Applications, D. Van Nostrand Co.)

our judgments of length are influenced by the amplitude of the ocular excursions made in traversing an object. In judging the length of the lines in Figure 52(a) the eyes tend to be impeded by the inward jutting arrow-heads, and encouraged to go farther forward by the outflaring "feather" ends. The excursion is therefore greater in one case than in the other;

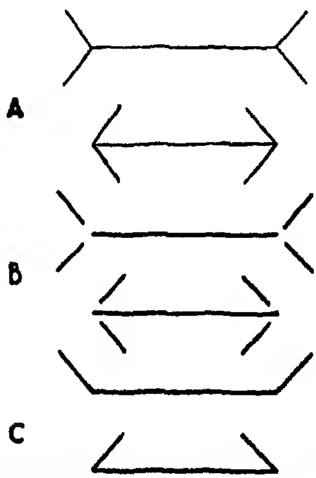


*Fig. 52.* Müller-Lyer figure with variations.

accordingly the horizontals are perceived as unequal in length. Photographs taken of the eyes during observation of the figures showed a difference in the movements for the two forms. Unfortunately for the theory the illusion is present during exposures too brief to permit eye movements. It has been suggested, moreover, that the differences in movement, when present, may be the *result* of the apparent difference in the length of the lines, rather than the cause. It has been found that the illusion may be made to disappear with extensive practice provided the figures are exposed long enough to permit eye movements. If the exposures are too brief for such movements the illusion does not disappear entirely despite extended practice. This fact indicates, according to Carr,[161] that eye movements are one of the factors involved. The eye movement theory, however, falls short of complete explanation.

The interpretation here of the *perspective theory* is related to the earlier discussion of the relation of distance to size. As applied to the Müller-Lyer figure it makes the apparent difference in length the result of an apparent difference in distance. In the first form of Figure 52 the horizontal line of the arrow-head figure, according to this theory, is perceived as *nearer* than that with the feather ends; correspondingly it is perceived as *smaller*, or shorter. The distance difference is the primary effect; the apparent size difference is a consequence. Figure 53

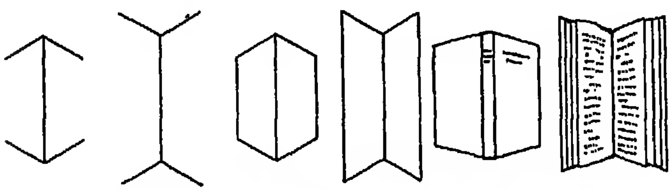

*Fig. 53.* Illustration of the perspective theory.

will make the matter clearer. The forms are seen as book-like outlines in which the backs are represented as at different distances, owing to the perspective lines. The vertical lines here subtend equal distances on the retina; the illusion arises from the inability to disregard the distance signs during the size judgment. Several other theories have been offered to account for this illusion.[162]

The distorting influence of perspective is interestingly shown in Figure 54. Of the four crosses drawn on the sides of the cube two are rectangular and two are oblique angles. Owing

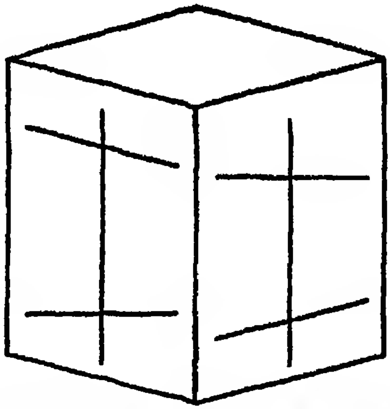

*Fig. 54.* Perspective illusion. (From Luckiesh, Visual Illusions and Their Applications, D. Van Nostrand Co.)

to perspective the right angles appear oblique, the oblique angles rectangular, as a little study will show.

The Poggendorff illusion, Figure 55, is one of the most famous of the geometrical group. At least ten explanations, according to Pierce, had been offered for it by 1901. The oblique line to the right of the verticals is a direct prolongation

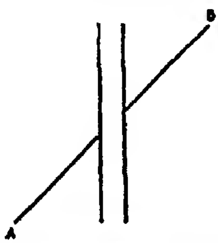


*Fig. 55.* The Poggendorff illusion.

of the oblique line to the left, but does not appear to be so. According to the eye movement theory the eyes, in passing over the interrupted line are deflected by the verticals and these disturbances result in the illusory impression. The perspective theory would propose that the oblique line is seen as

extended in the third dimension, as a horizontal line seen "in perspective." The acute angles made with the verticals are thus seen as larger—tending to right angles—than they really are. This impression entails a rotation, so to speak, of the obliques around the points of juncture, tending toward the horizontal plane, i.e. toward right angles with the verticals. As a result of this, supposedly, the two lines appear to be discontinuous. Pierce believes this illusion to be the product of a complex of different influences.

The illusion of Figure 56 is marked and rather striking. The diagonals drawn in the two parallelograms are equal in length. According to the *confluence theory* the apparently

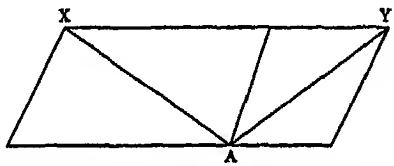


*Fig. 56.* The diagonals in the parallelograms are of equal length.

longer diagonal is so perceived because it forms a part of a truly larger parallelogram. A part of a larger object will be taken, generally, to be larger than a corresponding part of a smaller one. In the figure shown, the lack of actual correspondence between the positions of the diagonals is obscured by the strong influence of the difference in areas.

A filled space is perceived as greater in extent than an unfilled space of the same magnitude (Figure 57). The application of the eye movement theory readily suggests itself. The eyes would tend to be impeded in passing across the filled space,—

*Fig. 57.* Illusion of filled and unfilled space. (From Luckiesh, Visual Illusions and Their Applications, D. Van Nostrand Co.)

an effect which would operate to make the distance seem greater. Impeded eye movements, however, were used in the Müller-Lyer figure to account for an impression of relative shortness. The inconsistency is apparent.

In Figure 58 the total length of the series of three circles is equal to the distance between the upper circle and the one directly below it. In this case it may be that we are influenced by the greater distance between the two latter circles as wholes.

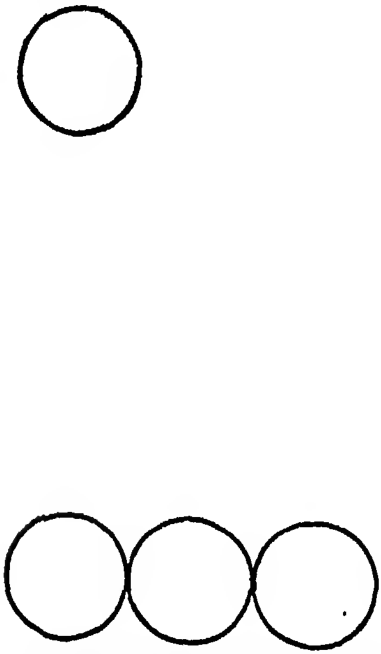

*Fig. 58.* (From Luckiesh, Visual Illusions and Their Applications, D. Van Nostrand Co.)

A large part of the study of geometrical illusions has consisted of correlating variations of certain elements of the figures with the amount of illusion experienced. With the Müller-Lyer figure, for example, the degree of illusion—the amount of apparent difference in the length of the horizontals—was found to increase up to a certain point as the length of the end-lines was increased, then to diminish as these lines were further lengthened. The illusory effect of the Poggendorf figure increases with the distance between the verticals and with the obliqueness of the interrupted line. It is reduced when the latter is held vertically or horizontally.

Many of the geometrical figures vary in illusory effect with variation in position in the visual field. The Zöllner illusion, for example (Figure 59), was found to be greatest when the

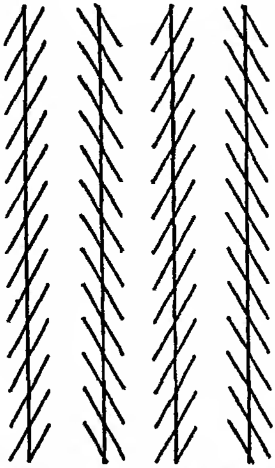

*Fig. 59.* The Zöllner illusion. The verticals are parallel.

verticals are held at about 45° from the upright position. An angle of maximal effect was likewise found for the inclination of the transversals. Zöllner, according to Luckiesh, accidentally

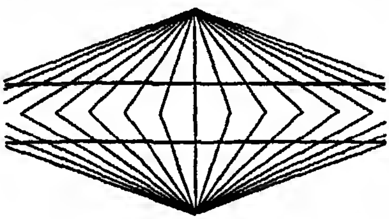

*Fig. 60.* Distortion of straight lines.

discovered the illusion in a pattern designed for dress goods. Figures 60 and 61 show two types of distortion of straight lines by the influence of the environing patterns. The lines converging through the horizontals deflect the latter in a direction opposite to that of the convergence.

Luckiesh[163] has interestingly described the occurrence of illusory effects in architecture and the means by which such impressions must be corrected. The horizontal beams resting

on the tops of the columns of a temple would exhibit a slight downward curve (Figure 62, *b*) if built straight, as in *a* of the

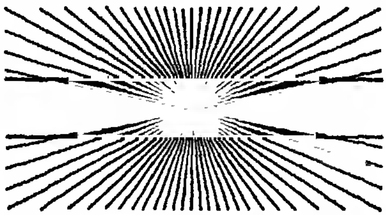

*Fig. 61.* Distortion of straight lines.

figure. The compensation necessary to eliminate this impression is shown in c. A similar correction must be made for the under-structure of the colonnade. In the famous Parthenon temple, Luckiesh states, this compensatory upward curvature is more than 4 inches from the horizontal on the sides, and about 2½ inches in front. (The scale of the distortions is of course enormously exaggerated in the figures.) The columns themselves must be built on an inward slant of some 3 inches (Figure 62, *c*); if built truly vertical, the illusory effect in *b* would result. The columns, further, must be constructed slightly larger at the mid-sections than at the tops and bases; this is to counteract an effect of shrunkenness when the pillars are straight.

A case which has been much studied is the vertical-horizontal illusion. Vertical distances are usually perceived as greater than equal horizontal distances (Figure 63). The illusion is present for exposures as brief as 1/50th second.[104] Marked differences in the amount of the illusion for right and left eyes may be present, though this difference is found in individuals entirely free from astigmatism.[105] Practice tends to increase the amount of the illusion, rather than diminish it, as is the case with certain other geometrical illusions. Wundt's eye movement theory—according to which vertical distance is overestimated because vertical excursions require greater effort, owing to more complex muscle movements—was ruled out when the illusion was found to be present with instantaneous exposures. According to the *esthetic theory,* lines and figures suggest feelings or thoughts which influence the perception of dimensions. Vertical lines suggest activity opposed to the force

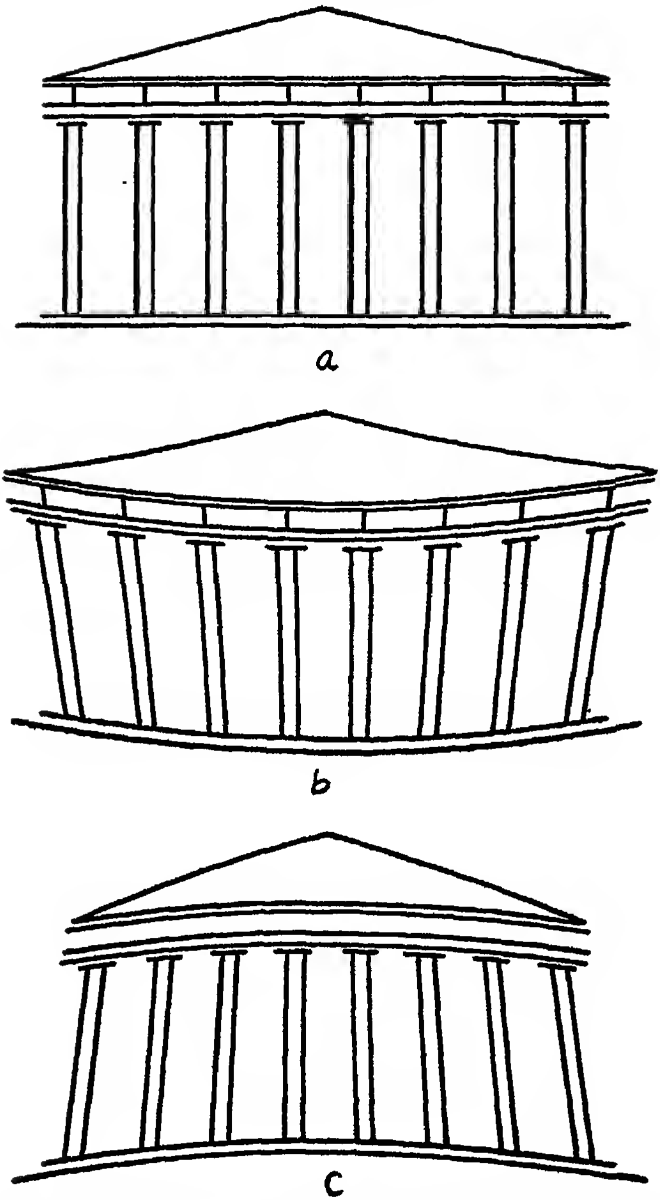

*Fig. 62.* Illustration of illusory effects in architecture. See text. (From Luckiesh, Visual Illusions and Their Applications, D. Van Nostrand Co.)

of gravity, an upward-striving force. This element is not contained in horizontal lines, which suggest rest and passivity. The vertical line has overcome gravity, therefore we see it as more "dynamic."

A third theory proposes that since the visual field is more extensive horizontally than vertically, a vertical line will be

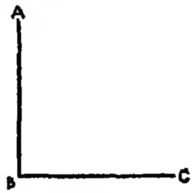

*Fig. 63.*

seen as longer because it occupies a relatively greater amount of the vertical field than a horizontal line does of the horizontal field. According to this the illusion should be smaller in degree if a single eye is used, since this reduces the horizontal field and should therefore lengthen a horizontal line, relatively. An experiment, however, gave no evidence that the illusion is greater binocularly.[166] The results of investigation were also unfavorable to the esthetic theory. The illusion was found in grade-school children; its amount diminishes with age from 8 to 14 years.

By having observers fixate the point *B* in Figure 63 while the two lines are rotated to various positions, apparent differences are found for all radii in the field.[167] The perceived length of a line depends on its location. The upper radius is seen as longest, the right is judged shortest, with the lower and left radii intermediate. A constant error is usually obtained in the attempt to bisect a horizontal line. These facts may rest on some fundamental peculiarity of the retina. Stevens[168] investigated this fact that perceptible size varies with retinal position. He used a large perimeter with two identical white cardboard discs which could be placed anywhere in the field. Black spots placed on the discs described circles when rapidly rotated; the diameter of these circles could be varied by shifting the position of the spots. The spaces enclosed within the circles were the objects whose sizes were compared when the discs were placed at two different points in the field; for example, equidistant

from the center on opposite sides of the same meridian. When the observer reported a difference in apparent size, the larger appearing disc was reduced until pronounced equal. The amount of necessary reduction was taken as a measure of the *apparent* difference when the discs were objectively equal.

Among the findings it was disclosed that an object in the upper part of the vertical meridian was judged definitely larger than when placed in the lower part at the same distance from the center. This was true for both eyes (one eye at a time being tested); the apparent difference in size increased with movement toward the periphery. The result checks with the observation that the upper half of a vertical line seems a bit longer than the lower half. It has often been noted that the upper and lower halves of the letter "S" and the figure "8" appear to be approximately equal in size; the actual difference emerges when the characters are inverted: "S," "8".

Theories as to the causes of geometrical illusions are many and various. The structure of the retina and the dimensions of the visual field; eye muscle movements and tendencies to move; esthetic reactions; perspective effects—these are merely among the most prominent of them. The fact that the illusion disappears with practice in the case of the Müller-Lyer, Zöllner and Poggendorf figures has been offered as evidence that it is psychological in nature in these instances. An illusion resting on optical laws or retinal physiology will not be abolished by repetition. Helmholtz maintained that what can be overcome by experience must be considered as itself the product of experience. Whether the dictum applies here is an issue. The radial disparities do not yield to practice, tend rather to be increased by it; the fact seems to justify placing the vertical-horizontal illusion in a different class.

Lewis[169] found that the disappearance of the Müller-Lyer illusion with practice was entirely unconscious. The subjects were greatly surprised when shown, at the end of practice, the lines which at the beginning had looked equal to them (after correction for the illusion by extension of the lines). The only conscious consequence of practice was the overcoming of

the distracting influence of the end-lines of the figures. The lines to be compared emerged into greater prominence, a habit of selective attention having been formed. Others have observed that the illusion is overcome more quickly when an effort is made from the start to isolate the essential lines by excluding attention from the others. On the other hand, practice with the intention of seeing the figure so far as possible as a whole led to an increase of the degree of illusion.

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